United States
Department of
Agriculture

Forest Service

GTR WO-58

Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States

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U.S. Department of Agriculture
Forest Service

General Technical Report WO-58

December 1990

Abstract

One approach to limiting the buildup of carbon dioxide (CO_2) in the atmosphere is to sequester carbon in forests. Several reports have estimated the amount of tree planting and the associated costs that would be required to significantly effect the net release of CO_2, but they have largely been "back of the envelope" calculations. This report employs detailed data on actual planting practices, amounts of marginal agricultural land, average merchantable timber yields, historic rental rates, and the ratio of total ecosystem carbon to timber carbon to calculate the incremental amount of carbon that could be sequestered by a rural tree planting and forest management program in the United States. Marginal and total cost curves indicate the relation between costs and the extent of the sequestering program.

Highlights

- An extensive tree planting and forest management program could sequester as much as 807 million short tons (56.4 percent of the current annual U.S. CO_2 releases) at an annual cost of $19.5 billion.

- A program to reduce U.S. net emissions of CO_2 by 20 percent would involve 138.4 million acres and cost $4.5 billion per year, or an average of $15.73 per short ton.

- The costs of carbon sequestering range from $5.26 to $43.33 per ton.

- Some of the least costly opportunities for carbon sequestering are on forestland and marginal pastureland, although the largest portion of the carbon capture in a program involving reductions of 10 percent or more must be on marginal cropland.

- The geographic distribution of marginal land indicates that such a planting program would be largely concentrated in the Southeast, Appalachia, and the Gulf States.

Acknowledgments

The authors acknowledge the useful review comments by George Peterson, USDA Forest Service, Rocky Mountain Station, and William Kurtz, School of Forestry, Fisheries and Wildlife, University of Missouri–Columbia. Also, Researcher Michael Fosberg, USDA Forest Service, Washington, D.C., assisted with the development of carbon factors for wood.

Contents

Introduction

While the U.S. Government is studying the science of global climate change, it also is evaluating policy options for affirmative action to reduce risks associated with the greenhouse effect. The principal ways to decrease the emissions of carbon dioxide (CO_2), the primary contributor to the greenhouse effect, are increasing energy efficiency and switching to nonfossil or low-carbon fuels. These changes may be achieved directly through Government intervention and regulation or indirectly through taxation and related marketable permits.

Alternatively, the Government may wish to consider achieving a portion of its CO_2 reduction goals by considering the effect that tree planting and modified forest practices could have on *net* emissions (that is, the total CO_2 emissions less the CO_2 sequestered in new forest plantings). To evaluate this forestry potential, the Government should compare the cost of carbon sequestering through tree planting with the cost of carbon emissions avoidance achieved through investments in energy efficiency and alternative energy sources. While there have been several studies that have evaluated the costs of carbon sequestering (Dudek 1988, Marland 1988, Sedjo 1989), their analyses generally have not considered that, as with most production or extraction processes, there is an increasing marginal cost of sequestering carbon.

This report examines the potential contribution that a large-scale rural tree planting and forest management program could make toward reducing net CO_2 emissions in the United States. The land areas in the hypothetical program include economically marginal and environmentally sensitive croplands and pasturelands, as well as forestlands held by private owners other than the forest industry.

Trees would be established on agricultural lands principally by planting trees, although direct seeding would be used in some instances (for example, certain bottomland hardwood species). For existing forestlands, both tree planting and natural regeneration methods would be used to treat poorly stocked stands of trees. Other practices for forestlands include the elimination of indiscriminate livestock grazing and timber harvesting, both of which result in damaged and understocked timber stands, and the replacement of decadent trees with faster growing, younger trees.

Public lands are not considered in this report, in large part because the public ownership of croplands and pasturelands is negligible. The public does control a large and important range resource, but trees are not the dominant form of natural vegetation on rangelands. Therefore, these lands offer comparatively few opportunities for large-scale forestry programs. Likewise, public forestlands offer only a limited opportunity for expanded reforestation because, as a matter of law and policy, regeneration is already taking place on these lands following timber harvests, fires, and other disturbances. The forest industry in the United States in recent decades also has been very active in managing forestlands for increased productivity.

The data regarding planting and management costs and mix of tree species are from practices developed jointly by the U.S. Department of Agriculture (USDA) Forest Service and State foresters and approved

by county Agricultural Stabilization and Conservation (ASC) committees. As such, these calculations comprise the most detailed, and perhaps realistic, analysis available of the costs of and potential for CO_2 sequestration through tree planting.

The primary focus of this report is on the direct social costs of such a program—the sum of the full cost of establishing trees and the market rental value of the land without consideration of whom would bear the cost (Government or private interests) or how that burden would shift over time. These costs are projected over a period of 40 years, which is within the lifespan of all tree species considered. Some species, of course, are commonly grown for periods of more than 80 years. However, 40 years was considered to be a reasonable planning horizon, given the expansion in scientific knowledge concerning the phenomena of global climate change, improvements in the efficiency of energy use, and such that are likely to occur over the next 40 years.

Because of the 40-year planning horizon, questions relating to carbon flows associated with the final dispositions of timber stands, including timber harvesting and carbon storage in forest products, are not addressed in this report.

The principal result of this analysis is the production of two cost curves for the fixation of carbon through tree planting and forest management. The first is a total cost curve that shows the total annual cost of a program associated with a given level of annual carbon sequestering. The second is a marginal cost curve that is used for comparing the costs of carbon sequestering with the costs of carbon emissions reductions. This allows the policy analyst to examine the cost per ton of carbon sequestered, at the margin, of a given size of program.

The Model

The model employed for developing the cost curves was very simple.

Basic Notation and Calculations

The following is the basic notation used in the model:

LA^ij = acres of land type i in farm production region j, i=1...x, j=1...y.

R^ij = annual rental cost in dollars per acre of land type i in region j.

P^ij = tree planting/treatment cost in dollars per acre (that is, capital cost) on land type i in region j.

Y^ij = annual incremental yield (cubic feet per acre per year) of merchantable wood on land type i in region j.

K^i = conversion factor (dimensionless) for the ratio of incremental increase in carbon in forest ecosystem (entire tree, soil, surface litter, and understory growth) to incremental increase in carbon in merchantable wood on land type i.

D^ij = density (tons per cubic foot) of carbon in the merchantable wood grown on land type i in region j.

The annual incremental carbon (C) uptake per acre on land type i in region j is calculated as:

$$C^ij = Y^ijK^iD^ij$$

The potential total national carbon (TC) uptake is:

$$TC = \sum_i \sum_j [LA^ij][C^ij]$$

The cost ($T\$$) associated with reaching the total national carbon uptake is:

$$T\$ = \sum_i \sum_j LA^ij[R^ij + A(r,n)P^ij]$$

where $A(r,n)$ is the annualized cost of the capital investment P, spread over the n years of the project life, at a discount rate of r.

The average cost per ton of carbon is simply:

$$AC = T\$/TC$$

Carbon can be converted to CO_2 on a weight basis by multiplying by a factor of 3.667, derived by dividing the molecular weight of carbon dioxide (44) by the molecular weight of carbon (12).

Procedure

The procedure involved the following six steps:

1. For each of the 10 USDA farm production regions (figure 1 in appendix B), identify and list potential program land areas by land type, segregating according to relevant dimensions (for example, soil, region, climate, erodibility, slope, and current use and condition).

2. Match each land type with an appropriate forestry treatment, such as planting, natural regeneration, and so forth, and with an appropriate mix of species.

3. For each land type in each region, determine the likely rental cost per acre.

4. For each land type in each region, determine the treatment cost and rental cost per acre.

5. For each land type in each region, with its associated forestry treatment, determine the expected incremental annual yield of merchantable wood per acre. The total incremental carbon yield per acre is derived by multiplying the merchantable wood figure by a conversion ratio that may be land type specific. Each of the forestry treatments will have a certain mix of species, and each of those species will have a specific density of carbon. The product of the incremental merchantable wood yield, the specific carbon density of the wood, and a factor relating carbon in merchantable wood to total forest ecosystem carbon determine the carbon fixation rate for each land type in each region.

6. Calculate the gross carbon fixation costs as:

   [Capitalized planting costs + rent]/carbon fixation rate.

The model thus far provides only total yields and total and average costs of a program that uses all marginal lands—the largest possible program. The effect on total and marginal costs of limiting the size of the program may be calculated as follows:

1. By arranging each land type in each region (LA^ij) in ascending order according to its associated carbon fixation cost, the land areas that capture carbon most cheaply are at the top of the list and the most expensive are at the bottom.

2. The marginal cost curve is derived by plotting the carbon fixation cost ($ per ton) in the ascending list against the cumulative tons sequestered.

3. The total program cost of a given amount of carbon sequestering is derived by plotting the cumulative cost (cost = [$ per ton] x [tons per acre] x [acres in LA^ij]) against the cumulative tons sequestered.

Data Collection

The data were largely derived from USDA sources, such as the Soil Conservation Service National Resources Inventory (NRI), Economic Research Service land rental data, and Agricultural Stabilization and Conservation Service reports and computer files for the Conservation Reserve Program (CRP). The tables referenced in the following subsections are in Appendix A.

Land Area and Type

The target acres are economically marginal and environmentally sensitive croplands and pasturelands and non-Federal forestlands on which growth rates could be increased. Marginal and environmentally sensitive agricultural lands were defined by the use of soil erosion rates in the current land use and by the land's suitablity for agricultural use according to its land capability class (LCC).

One of the criteria for selecting land was soil loss tolerance, T, which is the maximum average annual rate of soil loss that a specific soil can sustain without suffering a decline in its long-term productivity. The value of T ranges from 1 ton to 5 tons of soil loss per acre per year, but it is 5 tons per acre per year for about 70 percent of all soils.

Agricultural lands also were evaluated on the basis of the eight classes of land (I to VIII) in the Land Capability Classification System, which groups soils according to their ability to produce commonly cultivated crops and pasture plants without degradation or productivity loss. Class I soils are the best and have no severe limitations. Classes II through VIII indicate progressively greater limitations and narrower choices for agricultural use. All of the classes except I are divided into subclasses to indicate the dominant limitation for agricultural use. Those subclasses are "e," where erosion or damage from erosion is the dominant hazard; "w," to indicate excess water; "s," to indicate limiting soil conditions such as shallowness, stoniness, or salinity; and "c," where climate is the major limitation. For CRP, a combination of the measures has been used to determine eligibility for inclusion (USDA ASCS 1989a, p. 8).

Subclass "w" soils are of special interest to this study because of their potential to contribute to the pollution of surface water and groundwater supplies when they are used in agricultural production. While subclass "w" soils, hereafter often referred to as "wet soils," include wetlands, wet soils influence a much larger area of land that is wet because of poor soil drainage, high water tables, or flooding.

Cropland—Table 2 in appendix A lists the potential cropland area by State and region. There are three types of cropland that could be included beneficially in a tree planting program: (1) land eroding at rates greater than the tolerable rate, T; (2) land in LCC V to VII; and (3) land classified as wet soil. The areas of highly erodible land, in the second column of Table 2 are drawn from USDA SCS 1989b, appendix table 10. The cropland in LCC V to VII, the third to fifth columns of table 2, is from Resources Conservation Act (RCA) Appendix table 3a. However, these figures must be adjusted to avoid double counting with the erodible land in the second column.

There are 19.3 million acres of U.S. land in LCC V to VII (USDA SCS 1987, table 25b), not including Alaska and the Caribbean territories. Of these acres, 7.4 million have already been included in the erodible land of the second column. Assuming that the 62 percent figure can be applied uniformly throughout the United States, the sixth column shows the sum of the third through fifth columns, adjusted down by 38 percent.

The figures for wet cropland in the seventh column of table 2 are taken from the Draft RCA appraisal (USDA SCS 1989b, p. 11-9, table 11-5). There is likely very little double counting with the previous columns because wet soils are generally on relatively level land, which would not figure prominently in the erodible land or in the LCC V to VII.

Pastureland—Table 3 lists the potential pastureland area by State and region. As with cropland, this analysis recognizes three types of pastureland that could be beneficially included in a tree planting program: (1) land eroding at rates greater than the tolerance rate, T; (2) land in LCC VII and VIII; and (3) land classified as wet soil.

The areas of highly erodible pastureland in the second column of table 3 are drawn from table A4-11 of the Draft RCA Appraisal (USDA SCS 1989b). Land in LCC VII and VIII, the third and fourth columns of table 3, is from the Second RCA Appraisal (USDA SCS 1989b), appendix table 3b. As with cropland, these were adjusted to reflect land already accounted for as erodible land in the second column. There are 9.8 million acres of LCC VII and VIII pastureland in the United States, of which 38 percent is included in the second column. Assuming this figure is constant across the States, the third to fifth columns reflect the 62 percent of LCC VII and VIII that is not reflected in erodible lands. There is a total of 116.4 million acres of pastureland in LCC II, III, IV, and VI in the United States, of which 25.6 million, or 22 percent, is wet soils (USDA ASCS 1989a, table II-A). Based on the assumption that this rate is constant across all States, figures for wet pastureland were derived (USDA SCS 1989b, appendix table 3b). The results are presented in the sixth through tenth columns in table 3.

Forestland—Forestland area, listed in table 8, is categorized as either grazed or ungrazed. The marginal areas of these two categories were further classified according to which of the following three treatment types was most appropriate:

1. *Planting trees*—These stands are in such poor condition that there is no practical option but to replant. This land may be dominated by brush and scrub growth that precludes the natural establishment of trees, or there may be no natural seed source for natural regeneration. The figures for grazed and ungrazed forestland are taken from the fifth column of tables 14a and 13a, respectively, of NRI Basic Statistics (USDA SCS 1987a).

2. *Improved management of existing stands (passive management)*—The treatment in these areas would consist of placing the land under formal management agreements that require owners to reduce or eliminate grazing and to avoid overharvesting practices that leave the stand so understocked that the growth does not fully utilize the site. This also would involve some erosion control practices. The figures for grazed and ungrazed forestland requiring passive management are from the fourth and seventh columns of tables 14a and 13a, respectively, of the NRI Basic Statistics (USDA SCS 1987a).

3. *Improved management of existing stands (active management)*—These are stands best managed through active steps, such as the removal of cull and other slow-growing trees and soil preparation to promote natural regeneration of vigorous new trees. Figures for these grazed and ungrazed areas were drawn from the sixth column of tables 14a and 13a, respectively, of NRI Basic Statistics (USDA SCS 1987a).

Rental Rate

Annual rental rates are the most subjective (and hence the most difficult to estimate) figures included in the model. The estimates used here are conservative, reflecting the assumption that it will take significant additional incentives to encourage landowners to make long-term commitments to tree planting. Ultimately, only actual implementation of a program will reveal whether these figures are realistic. The figures on which these estimates are based are shown in table 10, "Derivation of Land Rent Figures."

Cropland—The following three sets of data help estimate cropland rental rates under a Federal tree planting program:

1. Conservation Reserve Program rental rates for the first seven signups, from table 4 of the supplement to the CRP Progress Report (USDA ASCS 1990). There are also data for the acres bid and the bid rental rates, as well as the acres contracted and contract rental rates for the first through the fourth signups (table III-A, USDA ASCS 1989a). The U.S. average contracted rental rate for CRP increased steadily from $42.06 per acre in the first signup to $53.38 per acre in the fourth.

2. Rental rates in the private sector for dry cropland (that is, not irrigated) in 1987 and 1988 (table 3, USDA ERS 1989c). For most States, CRP average rates are above those for the private market.

3. The average purchase or sale value of dry cropland in the private market (table 2, USDA ERS 1989c).

An interesting insight is gained by examining the ratio of average rental to average sale prices for each of the States. That ratio ranges from 0.5 percent to 0.8 percent for States such as Massachusetts, Delaware, and New Jersey and from 9 percent to 11 percent for South Dakota, Nebraska, and Wyoming. The CRP rental rates have been nearly double the private rental rates. If the low ratios in the Northeast are caused by land speculation, it may be very difficult to get landowners to make long-term commitments to tree growing in that region. And the high ratios in the Northern Plains and Mountain regions indicate that it may be less expensive to purchase land for tree growing than to rent it. An alternative explanation for the differences between CRP and market rental rates may lie within the two sets of data. CRP acres tend to be clustered in certain localities where land values and rental rates, in some instances, may not be accurately portrayed by State average rental rates. Also, CRP rental rates are fixed for the 10-year contract period, and farmers may simply be bidding higher to allow for expected increases in market rates over the contract period.

The final estimates of cropland rental rates were, as mentioned above, relatively subjective. They were based primarily on the CRP rental rates, adjusted upward by 10 to 15 percent—to reflect that the most eager renters have already entered the program and adjusted upward an additional 5 to 10 percent for those regions in which land values were very high relative to private rental rates. In no case was the rental rate allowed to exceed 20 percent of the land value.

Pastureland—State-by-State figures for private rental rates on pasturelands were adjusted to estimate program rental rates (table 2, USDA ERS 1989c). The expected rental rate for pastureland was derived by multiplying the expected cropland rental rate by the ratio of private grazing land rental rates to private cropland rental rates.

Forestland—Forestland was expected to have the lowest opportunity cost of any

land type and was accordingly assigned a rental rate equal to 35 percent of that of the pastureland for the same region.

Treatment Cost

Treatment cost per acre, shown in column 3 of table 1, varies according to the land type and the region of the country. The figures include total costs (public plus private) for the entire treatment, which in the case of tree planting includes the seedlings, planting, site preparation, and postplanting treatment and care required to ensure establishment. No allowance was made for subsequent costs that owners may incur for practices such as precommercial thinnings, release cuttings, and pruning. Although such practices may frequently enhance the production of commercial timber products, it does not necessarily follow that the ability of stands to sequester carbon will be increased.

Cropland—The figures in Table 1 for wet and dry cropland treatment costs were derived from the second column of tables 4 and 5, respectively. For each region, the costs reflect a given mix of tree species, based on historical planting patterns. In some regions, costs vary slightly between wet and dry areas because of differences in species mix. For example, although Douglas-fir was the single most important species on the drier erodible cropland in the Pacific region, it is not as prevalent in the wet soils planting in that region because it does not thrive in wet soils.

Species mix and planting practice costs for dry soils were derived from ASCS Conservation Reporting and Evaluation Systems files, based on special runs by the Forest Service. For wet soils, the species were modified according to Forest Service figures (USDA FS 1983a).

Pastureland—The treatment of pastureland is identical to that for cropland, except that additional costs are incurred for initial preparation (soil preparation, weed control, and so on). The fact that treatment costs are generally higher for pastureland than for cropland reflects this additional requirement, as shown in tables 6 and 7.

Forestland—As mentioned above, the grazed and ungrazed marginal, non-Federal forestland areas can be distinguished as to treatment type required. Each of these treatment costs carries a unique cost figure, as follows:

1. *Planting trees*—The figures for this activity were derived from Forest Service figures (table 9.4, USDA FS 1988). Because the regions do not correspond exactly to the regions used in this study, some transposition of State cost figures was required.

2. *Passive management*—This treatment may be as simple as requiring the landowner to close gates, but it also may in some cases require new fencing or other expenses. Expert advice indicated the cost to be approximately $4 per acre.

3. *Active management*—The figures for active management also were derived using the stocking control figures (table 9.4, USDA FS 1988). The derivation of these figures required the same assumptions, transposing, and calculations as the derivation of the planting trees figures.

Incremental Carbon Capture

Column 4 of table 1 is an estimate of the additional annual uptake of carbon per acre for each region and soil type. It is composed of the product of the following three factors:

1. The incremental gain in cubic feet of merchantable (commercially salable) wood per acre per year (Risbrudt and Ellefson

1983, table 16; USDA 1983b, Appendix C).

2. The ratio of the carbon contained in the incremental increase in the trees, soil, and surface litter to the carbon contained in the incremental merchantable wood.

3. The carbon density in pounds per cubic foot of wood.

The Forest Service has collected extensive data on the first factor, which varies with the land type, region, and treatment of the area. The figures for the carbon ratio are derived from recent research conducted by the Forest Service (Birdsey 1990a, b). Those conversion factors range from 1.9 (pines planted in Northeast forestland) to 8.4 (spruce planted in various soil types and regions). Specific gravities for wood by tree species were obtained from the *Wood Handbook* (USDA FS 1987b). The final factor, carbon density, has been estimated by Brown (1988) for a variety of species of trees.

Cropland—The ninth column of tables 4 and 5 represents the annual capture of carbon. These figures are derived by dividing the product of the fourth, sixth, and seventh columns by 2,000 to convert pounds to tons. The wet soils generally have a higher yield of wood than the dry. For example, yields of loblolly pine and slash pine are approximately 20 percent higher in wet soils. While these species adapt to a wide variety of sites, both achieve their optimal growth on wet soils.

Pastureland—Wet and dry pastureland yields of merchantable wood are expected to follow patterns similar to cropland, with a 15-percent reduction to reflect problems of competing weeds and a generally inferior quality of soil.

Forestland—The incremental carbon yield for forestland was calculated in much the same way as for cropland. For the treatment types "planting trees" and "active management," the incremental yield of merchantable wood was drawn from table 9-4 of USDA (1988). This is shown on a regional basis in the last column of the respective sections in table 8. Each regional yield of merchantable wood for planting trees and active management was distributed among the various species for that region, based on the area weight (the second column) of the species. The merchantable wood yield by species and region is shown in the columns titled "Merch. wood" under the headings "Planting trees" and "Active management" in table 9. The figures for merchantable wood were multiplied by the carbon density figures (the fourth column) and the total carbon ratio (the fifth column) to derive the yield of carbon for planting trees and active management, as shown in table 9. The incremental yield of merchantable wood (and hence carbon) for passive management was estimated as 50 percent of that for active treatment.

Annualization of the Treatment Cost

To provide comparability to annual rents and annual incremental yields of carbon sequestering, the treatment costs were annualized. A period of 40 years was chosen to reflect a reasonable lifetime for a program of this magnitude. Longer periods would have little effect on the relative contribution of the treatment cost to total cost. An interest rate of 10 percent was assumed, yielding a capital recovery factor of 0.10226 (column 5, table 1). This factor was multiplied by the treatment cost to yield an annual cost equivalent for the treatment cost (column 6, table 1), and this was added to the annual rent, to produce a total annual cost in dollars per acre, shown in column 7 of table 1.

Unit Cost of Sequestering Carbon

In table 1, the cost per ton of carbon

sequestered (column 8) was calculated by dividing the total annual cost per acre (column 7), by tons of carbon per acre per year (column 4) for each region, land type, and soil type. For example, it costs $37 per ton to use dry cropland in the Corn Belt to sequester carbon, but it is only $22 per ton to use planting on forestland in the Northeast.

Carbon Sequestering Potential

Column 9 of table 1 shows the total carbon capturing potential of each land type in each region. This was derived by simply multiplying the total land area (column 1) for each land type by the incremental yield per acre for that land type (column 4). This suggests that while only 1.1 million tons of carbon could be captured using the dry pastureland in the Northern Plains region, 105.2 million tons could be captured if all of the marginal wet cropland in the Corn Belt were used.

Development of Cost Curves

The final cost curves were derived by sorting the various regional land types in ascending order according to their unit cost figures in column 8 of table 1. This configuration helps identify the tree planting areas that provide the least cost capture of carbon, the tons of carbon that can be sequestered at those costs, and the number of acres involved in each area. The results for the initial data and assumptions are shown in table 1A. From this table, two types of cost curves were developed. The total cost curve is a graph of the total cost of a carbon sequestering program as a function of the number of tons of carbon captured. The marginal cost curve is a graph of the marginal cost of an additional ton of carbon capture as a function of the total tons of carbon captured. This helps answer the question: "If we are already capturing 100 million tons of carbon, what would be the cost of capturing an additional ton?"

Results and Discussion

The total and marginal cost curves are displayed in figures 2 and 3, respectively. Along with tables 1 and 1A in appendix A, these results lead to the following relevant observations.

- Based on an estimated current annual U.S. net emissions of carbon (in the form of CO_2) of 1.4 billion short tons per year, a tree planting and management program limited to marginal agricultural and forestland could achieve as much as a 56.4-percent decrease in net emissions.

- The cost of a program to achieve a 56.4-percent reduction would be approximately $19.5 billion per year. As shown in table 11, the annual cost of achieving 10-, 20-, and 30-percent reductions would be approximately $1.7, $4.5, and $7.7 billion, respectively.

- The marginal cost of carbon captured in programs designed to reduce net CO_2 emissions by 10, 20, 30 and 56 percent is $16.9, $20.9, $23.6, and $43.3 per ton, respectively.

- As shown in table 11, a least-cost program to reduce net emissions of CO_2 by 10 percent would involve approximately 71 million acres. Of this, 22.2 million (31 percent) are pastureland, 36.9 million (52 percent) are forestland, and 11.8 million (17 percent) are cropland (figure 4).

- As shown in table 11, the average cost of achieving 10-, 20-, and 30-percent offsets would be $12.02, $15.73, and $17.91 per ton, respectively.

- The costs of the program are dominated by land rental costs, with the establishment or planting costs generally constituting less than 40 percent of total annualized costs on the crop and pastureland.

- One area of concern is the extent to which a tree planting program would compete with other productive uses of the land, particularly crop production. First, it must be emphasized that this analysis has been limited in scope to economically marginal and environmentally sensitive croplands, pasturelands, and forestlands on which growth rates of trees could be enhanced. Second, as the results in table 1A and figure 4 indicate, the first 10-percent (143 million tons per year) offset would involve relatively little cropland. As indicated in Figure 5, however, the relatively few acres of cropland that are included at the 200-million-tons-per-year level provide a disproportionate share of the carbon sequestration. This is because of the contribution of relatively inexpensive but productive cropland in the Mountain region. Beyond 200 million tons per year, virtually all of the significant capacity is on cropland.

- Because most of the costs associated with a large-scale planting program are in the rental or land opportunity costs, the effect of the discount rate is not strong. As shown in Figure 6, at 800 million tons per year, lowering the discount rate from 10 percent (which was employed for this analysis) to 4 percent decreases the total annualized costs by approximately 10 percent.

- The relative number of acres used in each region depends on the size of the tree planting program (table 12). For example, a least-cost program designed

to offset 5 percent of total U.S. CO_2 emissions would involve no land from Appalachia, whereas in a 30-percent reduction program that region would have the highest share of acreage. In contrast, the Pacific region would have more acreage involved in a 5-percent program than any other region, but its contribution would increase only slightly in a 30-percent program, making it one of the least significant regions. At no level is a large acreage from the Northeast involved.

Limitations of the Analysis

The scope of this analysis is, by design, limited to the direct costs to society, measured in terms of the estimated expenditures required for tree planting and other forest practices and the implicit cost—as represented by market rental rates—of foregoing opportunities to continue alternative uses of the land. Such a program, of course, would affect society beyond these direct costs.

Fischman (1990) of the Environmental Law Institute has termed tree planting a no-lose option that provides enough social, environmental, and economic benefits to justify program expenses irrespective of the outcome of the greenhouse debate. Obviously, the scale of any such program would be an important factor. Increases in the scale of tree planting would very likely have a number of external effects, such as changes in soil erosion rates, water quality and water flows, wildlife populations and species composition, and measurable effects on other areas, including farm income and consumer prices for food.

The indirect impacts of CRP and other resource provisions of the 1985 Farm Bill are in some ways analogous to an expanded tree program, and various aspects of these programs have been reported. For example, see Moulton and Dicks (1987), Robinson (1987), Ribaudo (1989), Moulton and et al. (1989), and Young and Osborne (1990).

Another important feature of the study is that it does not consider the effects of timber harvesting on the carbon budgets of forest ecosystems. This is consistent within the focus of what could be done within an intermediate timeframe to offset atmospheric carbon dioxide and the 40-year planning horizon of the study, during which little harvesting of a final nature would need to occur. Birdsey (1990a) has looked at the release of carbon in harvesting and has related this to the increased rate of carbon dioxide assimulation associated with younger and faster growing replacement forest stands. In addition, Row (1990) has investigated the storage of carbon in forest products.

This analysis also does not consider the startup period for a tree planting program. The assumption has been one of "instant trees"—as if society has committed funds, and there will immediately be several million new acres of trees fixing carbon. In fact, a large-scale effort could take 5 to 20 years simply to plant the trees, depending on the number of acres involved, and then another 5 to 15 years for those trees to be fixing carbon at the rates used in this analysis. This inevitably will bring some costs forward, while delaying the environmental benefits.

There also are limitations to the material that is included in the analysis. As indicated under "Data Collection," the land rental rates have been particularly difficult to estimate. Here, we have attempted to use conservative estimates, 12 to 25 percent higher than the historic CRP rental rates, which, in turn, generally have been considerably higher than the private market rental rates. Notwithstanding, the rental rates, as well as all other estimates of costs, are first-order estimates. Further research should consider nonmarginal changes in costs associated with very large-scale reforestation in a general equilibrium context.

Similarly, the estimates of incremental timber yield are based on the historic performance of each region where the programs have not been designed to maximize carbon capture. With improved genetic strains, changes in the species mix, and management for optimizing CO_2 uptake, the yield of carbon capture

per acre could be improved considerably. Also, while the ratios relating merchantable wood carbon to total carbon in the forest ecosystem are the best available, further research on this critical factor is needed.

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Appendix A—Tables

Table 1—*Carbon Sequestering Potential of Domestic Tree Planting Program*

	1 Land area (thousand acres)[1]	2 Rental rate[2]	3 Cost of treat-ment[3]	4 Tons of carbon/ acre/yr[4]	5 Capital recovery factor[5]	6 Annualized treatment cost/acre/yr[6]	7 Total cost/ acre/yr[7]	8 Unit cost for carbon ($/ton)[8]	9 Carbon available (thousand tons/yr)[9]	10 Total cost ($million)[10]
Northeast										
Crop	10,958									
Wet	5,130	72.00	149	3.61	0.10226	15.2	87.2	24.1	18,535.7	448
Dry	5,828	72.00	151	3.04	0.10226	15.4	87.4	28.8	17,722.6	510
Pasture	2,554									
Wet	1,707	34.61	196	2.76	0.10226	20.0	54.7	19.8	4,708.9	93
Dry	847	34.61	196	2.31	0.10226	20.0	54.7	23.6	1,958.3	46
Forest	9,379									
Planting	2,422	12.11	140	1.20	0.10226	14.3	26.4	22.0	2,907.1	64
Passive Mgmt.	1,153	12.11	4	0.29	0.10226	0.4	12.5	43.3	333.1	14
Active Mgmt.	5,804	12.11	40	0.58	0.10226	4.1	16.2	28.1	3,354.6	94
Lake States										
Crop	24,811									
Wet	16,680	65.00	107	3.22	0.10226	10.9	75.9	23.6	53,719.6	1,267
Dry	8,131	65.00	103	2.61	0.10226	10.5	75.5	28.9	21,233.8	614
Pasture	2,610									
Wet	1,921	20.80	105	2.51	0.10226	10.7	31.5	12.5	4,826.7	61
Dry	689	20.80	105	2.06	0.10226	10.7	31.5	15.3	1,419.9	22
Forest	7,049									
Planting	3,545	7.28	132	2.04	0.10226	13.5	20.8	10.2	7,232.8	74
Passive Mgmt.	1,717	7.28	4	0.56	0.10226	0.4	7.7	13.7	966.9	13
Active Mgmt.	1,788	7.28	32	1.13	0.10226	3.2	10.5	9.3	2,013.8	19
Corn Belt										
Crop	78,013									
Wet	38,660	81.00	139	2.72	0.10226	14.2	95.2	35.0	105,234.1	3,681
Dry	39,353	81.00	133	2.56	0.10226	13.6	94.6	37.0	100,651.5	3,723
Pasture	10,198									
Wet	4,966	24.72	186	2.12	0.10226	19.0	43.7	20.7	10,508.9	217
Dry	5,232	24.72	186	2.00	0.10226	19.0	43.7	21.8	10,476.6	229
Forest	7,628									
Planting	1,835	8.65	132	2.33	0.10226	13.5	22.1	9.5	4,276.9	41
Passive Mgmt.	3,669	8.65	4	0.64	0.10226	0.4	9.1	14.1	2,361.0	33
Active Mgmt.	2,124	8.65	32	1.29	0.10226	3.2	11.9	9.2	2,733.3	25

	1	2	3	4	5	6	7	8	9	10
	Land area (thousand acres)[1]	Rental rate[2]	Cost of treat-ment[3]	Tons of carbon/ acre/yr[4]	Capital recovery factor[5]	Annualized treatment cost/acre/yr[6]	Total cost/ acre/yr[7]	Unit cost for carbon ($/ton)[8]	Carbon available (thousand tons/yr)[9]	Total cost ($million)[10]
Northern Plains										
Crop	24,056									
Wet	7,160	52.00	97	2.86	0.10226	9.9	61.9	21.6	20,491.9	443
Dry	16,896	52.00	97	2.61	0.10226	9.9	61.9	23.7	44,096.2	1,046
Pasture	2,247									
Wet	1,698	13.11	102	2.23	0.10226	10.4	23.5	10.5	3,793.9	40
Dry	549	13.11	102	2.03	0.10226	10.4	23.5	11.6	1,116.7	13
Forest	337									
Planting	28	4.59	132	3.07	0.10226	13.5	18.1	5.9	85.4	1
Passive Mgmt.	214	4.59	4	0.71	0.10226	0.4	5.0	7.1	150.6	1
Active Mgmt.	96	4.59	28	1.41	0.10226	2.8	7.4	5.3	135.6	1
Appalachian										
Crop	15,924									
Wet	6,020	61.00	62	3.47	0.10226	6.3	67.3	19.4	20,914.5	405
Dry	9,904	61.00	62	2.89	0.10226	6.3	67.3	23.3	28,668.7	667
Pasture	8,002									
Wet	3,341	27.81	89	2.48	0.10226	9.1	36.9	14.9	8,273.9	123
Dry	4,661	27.81	89	2.06	0.10226	9.1	36.9	17.9	9,619.9	172
Forest	14,264									
Planting	6,664	9.73	116	1.05	0.10226	11.9	21.6	20.6	6,994.7	144
Passive Mgmt.	3,836	9.73	4	0.44	0.10226	0.4	10.1	23.2	1,677.5	39
Active Mgmt.	3,764	9.73	47	0.87	0.10226	4.8	14.5	16.6	3,291.5	55
Southeast										
Crop	11,876									
Wet	4,690	51.00	61	3.38	0.10226	6.2	57.2	16.9	15,865.7	268
Dry	7,186	51.00	58	2.85	0.10226	5.9	56.9	20.0	20,473.6	409
Pasture	3,112									
Wet	2,484	26.75	67	2.46	0.10226	6.9	33.6	13.6	6,121.6	83
Dry	628	26.75	67	2.03	0.10226	6.9	33.6	16.5	1,275.8	21
Forest	15,168									
Planting	9,885	9.36	121	1.15	0.10226	12.3	21.7	18.8	11,415.2	214
Passive Mgmt.	1,314	9.36	4	0.48	0.10226	0.4	9.8	20.5	625.9	13
Active Mgmt.	3,969	9.36	47	0.95	0.10226	4.8	14.2	14.9	3,780.9	56

	1	2	3	4	5	6	7	8	9	10
	Land area (thousand acres)[1]	Rental rate[2]	Cost of treat-ment[3]	Tons of carbon/acre/yr[4]	Capital recovery factor[5]	Annualized treatment cost/acre/yr[6]	Total cost/acre/yr[7]	Unit cost for carbon ($/ton)[8]	Carbon available (thousand tons/yr)[9]	Total cost ($million)[10]
Delta States										
Crop	25,227									
Wet	16,350	50.00	70	2.62	0.10226	7.2	57.2	21.8	42,851.6	935
Dry	8,877	50.00	69	2.73	0.10226	7.1	57.1	20.9	24,191.3	506
Pasture	3,632									
Wet	2,335	16.21	77	2.31	0.10226	7.9	24.1	10.4	5,394.9	56
Dry	628	16.21	77	2.40	0.10226	7.9	24.1	10.0	1,508.8	15
Forest	7,240									
Planting	3,180	5.67	141	1.03	0.10226	14.4	20.1	19.5	3,278.3	64
Passive Mgmt.	1,606	5.67	4	0.41	0.10226	0.4	6.1	14.9	654.2	10
Active Mgmt.	2,454	5.67	48	0.81	0.10226	4.9	10.6	13.0	1,999.0	26
Southern Plains										
Crop	13,446									
Wet	6,050	47.00	57	2.84	0.10226	5.8	52.8	18.6	17,151.8	320
Dry	7,396	47.00	57	2.36	0.10226	5.8	52.8	22.4	17,473.2	391
Pasture	6,082									
Wet	4,611	12.73	63	2.50	0.10226	6.4	19.2	7.7	11,522.9	88
Dry	1,471	12.73	63	2.08	0.10226	6.4	19.2	9.2	3,062.7	28
Forest	3,840									
Planting	2,016	4.46	141	1.01	0.10226	14.4	18.8	18.7	2,034.6	38
Passive Mgmt.	927	4.46	4	0.40	0.10226	0.4	4.9	12.2	369.8	5
Active Mgmt.	897	4.46	48	0.80	0.10226	4.9	9.3	11.7	715.7	8
Mountain										
Crop	10,940									
Wet	2,470	45.00	70	3.76	0.10226	7.2	52.2	13.9	9,288.1	129
Dry	8,470	45.00	70	3.76	0.10226	7.2	52.2	13.9	31,850.3	442
Pasture	1,819									
Wet	1,427	20.42	109	3.08	0.10226	11.1	31.6	10.3	4,390.0	45
Dry	392	20.42	109	3.08	0.10226	11.1	31.6	10.3	1,206.0	12
Forest	5,069									
Planting	838	7.15	153	1.05	0.10226	15.6	22.8	21.7	879.5	19
Passive Mgmt.	3,204	7.15	4	0.28	0.10226	0.4	7.6	27.3	887.3	24
Active Mgmt.	1,026	7.15	19	0.55	0.10226	1.9	9.1	16.4	568.5	9

	1	2	3	4	5	6	7	8	9	10
	Land area (thousand acres)[1]	Rental rate[2]	Cost of treat- ment[3]	Tons of carbon/ acre/yr[4]	Capital recovery factor[5]	Annualized treatment cost/acre/yr[6]	Total cost/ acre/yr[7]	Unit cost for carbon ($/ton)[8]	Carbon available (thousand tons/yr)[9]	Total cost ($million)[10]
Pacific										
Crop	9,051									
Wet	3,770	58.00	180	2.48	0.10226	18.4	76.4	30.8	9,348.1	288
Dry	5,281	58.00	180	2.48	0.10226	18.4	76.4	30.8	13,115.9	404
Pasture	1,288									
Wet	920	12.43	215	1.81	0.10226	22.0	34.4	19.1	1,661.3	32
Dry	204	12.43	215	1.50	0.10226	22.0	34.4	23.0	306.3	7
Forest	8,989									
Planting	3,578	4.35	247	3.52	0.10226	25.3	29.7	8.4	12,596.6	106
Passive Mgmt.	3,041	4.35	4	0.36	0.10226	0.4	4.8	13.0	1,109.2	14
Active Mgmt.	2,370	4.35	36	0.73	0.10226	3.7	8.0	11.0	1,729.5	19

[1] Figures for cropland from table 2. Dry cropland is the sum of land in E>T and LCC=V+VI+VII. Pastureland areas are from table 3. Dry pastureland is the sum of the land in E>T and LCC=VI+VII. Forestland area is from table 7.

[2] Established land rental rates based on CRP and private market rates. See table 10 and the discussion in the text.

[3] Cost of all establishment activities. Cropland figures are from the second column of tables 4 and 5. Pastureland figures are from tables 6 and 7. Forestland figures are from table 8.

[4] Increment, in tons, of carbon captured by treatment, per acre per year. Wet and dry cropland figures are from tables 4 and 5. Wet and dry pastureland figures are from tables 6 and 7. Forestland figures are from table 9. The figures for passive management are estimated to be 50 percent of those for active management.

[5] Factor for annualization of capital outlays over 40 years at 10 percent.

[6] Annualized cost of capital outlays for treatment in dollars per acre per year.

[7] Total annualized costs per acre (sum of rental payment and annualized capital costs).

[8] Cost per ton of carbon captured. [Annual cost ($/acre/yr.)]/[carbon yield (tons/acre/yr.)]

[9] Annual potential for capturing carbon, in millions of tons. Land area (acres) x carbon yield (tons per acre).

[10] Total annual cost in millions of dollars. Land area (acres) x total annual cost ($/acre).

Table 1A—*Cost-Curve Development Table*

		$ per ton of carbon	Acres (thousands)		Tons sequestered (thousands)		Cost ($millions)		Acres		Carbon	
			Total	Cum.	per yr.	Cum.	Total	Cum.	Forest only	Forest + pasture	Forest only	Forest + pasture
				0		0		0	0	0	0	0
NP	Forest Active Mgmt.	5.26	96	96	136	136	1	1	96	96	136	136
NP	Forest Planting	5.89	28	124	85	221	1	1	124	124	221	221
NP	Forest Passive Mgmt.	7.08	214	337	151	372	1	2	337	337	372	372
SP	Pastureland Wet	7.67	4,611	4,948	11,523	11,895	88	91	337	4,948	372	11,895
PC	Forest Planting	8.42	3,578	8,527	12,597	24,491	106	197	3,916	8,527	12,968	24,491
SP	Pastureland Dry	9.21	1,471	9,997	3,063	27,554	28	225	3,916	9,997	12,968	27,554
CB	Forest Active Mgmt.	9.22	2,124	12,121	2,733	30,287	25	250	3,916	12,121	12,968	30,287
LS	Forest Active Mgmt.	9.32	1,788	13,909	2,014	32,301	19	269	3,916	13,909	12,968	32,301
CB	Forest Planting	9.50	1,835	15,743	4,277	36,578	41	310	5,750	15,743	17,245	36,578
DS	Pastureland Dry	10.03	628	16,371	1,509	38,087	15	325	6,378	16,371	18,754	38,087
LS	Forest Planting	10.18	3,545	19,916	7,233	45,320	74	398	6,378	19,916	18,754	45,320
MT	Pastureland Wet	10.26	1,427	21,344	4,390	49,710	45	443	7,806	21,344	23,144	49,710
MT	Pastureland Dry	10.26	392	21,736	1,206	50,916	12	456	7,806	21,736	23,144	50,916
DS	Pastureland Wet	10.42	2,335	24,071	5,395	56,310	56	512	7,806	24,071	23,144	56,310
NP	Pastureland Wet	10.54	1,698	25,769	3,794	60,104	40	552	9,504	25,769	26,938	60,104
PC	Forest Active Mgmt.	11.00	2,370	28,140	1,730	61,834	19	571	9,504	28,140	26,938	61,834
NP	Pastureland Dry	11.57	549	28,689	1,117	62,951	13	584	10,053	28,689	28,055	62,951
SP	Forest Active Mgmt.	11.71	897	29,586	716	63,666	8	592	10,950	29,586	28,770	63,666
SP	Forest Passive Mgmt.	12.20	927	30,513	370	64,036	5	597	10,950	30,513	28,770	64,036
LS	Pastureland Wet	12.55	1,921	32,434	4,827	68,863	61	657	12,871	32,434	33,597	68,863
DS	Forest Active Mgmt.	12.96	2,454	34,888	1,999	70,862	26	683	15,325	34,888	35,596	70,862
PC	Forest Passive Mgmt.	13.05	3,041	37,928	1,109	71,971	14	698	15,325	37,928	35,596	71,971
SE	Pastureland Wet	13.63	2,484	40,412	6,122	78,093	83	781	17,809	40,412	41,718	78,093
LS	Forest Passive Mgmt.	13.65	1,717	42,128	967	79,059	13	795	17,809	40,412	41,718	78,093
MT	Cropland Dry	13.87	8,470	50,598	31,850	110,910	442	1,236	17,809	40,412	41,718	78,093
MT	Cropland Wet	13.87	2,470	53,068	9,288	120,198	129	1,365	20,279	42,882	51,006	87,381
CB	Forest Passive Mgmt.	14.08	3,669	56,737	2,361	122,559	33	1,398	20,279	46,551	51,006	89,742
AP	Pastureland Wet	14.90	3,341	60,078	8,274	130,833	123	1,522	23,619	49,892	59,280	98,016
SE	Forest Active Mgmt.	14.91	3,969	64,047	3,781	134,614	56	1,578	27,588	53,860	63,061	101,796
DS	Forest Passive Mgmt.	14.93	1,606	65,653	654	135,268	10	1,588	27,588	55,466	63,061	102,451
LS	Pastureland Dry	15.30	689	66,342	1,420	136,688	22	1,610	28,277	56,155	64,480	103,870
MT	Forest Active Mgmt.	16.41	1,026	67,368	569	137,256	9	1,619	28,277	57,182	64,480	104,439
SE	Pastureland Dry	16.54	628	67,996	1,276	138,532	21	1,640	28,905	57,810	65,756	105,715
AP	Forest Active Mgmt.	16.62	3,764	71,760	3,291	141,823	55	1,695	28,905	57,810	65,756	105,715
SE	Cropland Wet	16.92	4,690	76,450	15,866	157,689	268	1,963	28,905	62,500	65,756	121,580
AP	Pastureland Dry	17.89	4,661	81,111	9,620	167,309	172	2,135	28,905	62,500	65,756	121,580

	$ per ton of carbon	Acres (thousands)		Tons sequestered (thousands)		Cost ($millions)		Acres		Carbon	
		Total	Cum.	per yr.	Cum.	Total	Cum.	Forest only	Forest + pasture	Forest only	Forest + pasture
SP Cropland Wet	18.63	6,050	87,161	17,152	184,461	320	2,455	34,955	68,550	82,908	138,732
SP Forest Planting	18.67	2,016	89,177	2,035	186,495	38	2,493	36,971	70,566	84,942	140,767
SE Forest Planting	18.78	9,885	99,063	11,415	197,910	214	2,707	46,856	80,451	96,358	152,182
PC Pastureland Wet	19.06	920	99,983	1,661	199,572	32	2,739	46,856	81,371	96,358	153,843
AP Cropland Wet	19.38	6,020	106,003	20,915	220,486	405	3,144	46,856	81,371	96,358	153,843
DS Forest Planting	19.46	3,180	109,183	3,278	223,765	64	3,208	50,036	84,551	99,636	157,122
NE Pastureland Wet	19.81	1,707	110,890	4,709	228,473	93	3,301	50,036	86,259	99,636	161,830
SE Cropland Dry	19.98	7,186	118,076	20,474	248,947	409	3,710	50,036	86,259	99,636	161,830
SE Forest Passive Mgmt.	20.52	1,314	119,390	626	249,573	13	3,723	51,350	87,573	100,262	162,456
AP Forest Planting	20.57	6,664	126,054	6,995	256,568	144	3,867	58,015	94,237	107,257	169,451
CB Pastureland Wet	20.67	4,966	131,020	10,509	267,077	217	4,084	58,015	99,203	107,257	179,960
DS Cropland Dry	20.94	8,877	139,897	24,191	291,268	506	4,591	58,015	99,203	107,257	179,960
NP Cropland Wet	21.63	7,160	147,057	20,492	311,760	443	5,034	58,015	99,203	107,257	179,960
MT Forest Planting	21.72	838	147,895	880	312,639	19	5,053	58,853	100,041	108,136	180,840
DS Cropland Wet	21.81	16,350	164,245	42,852	355,491	935	5,988	58,853	100,041	108,136	180,840
CB Pastureland Dry	21.84	5,232	169,477	10,477	365,967	229	6,217	58,853	105,273	108,136	191,316
NE Forest Planting	22.02	2,422	171,899	2,907	368,875	64	6,281	61,274	107,695	111,043	194,223
SP Cropland Dry	22.36	7,396	179,295	17,473	386,348	391	6,671	61,274	107,695	111,043	194,223
PC Pastureland Dry	22.96	204	179,499	306	386,654	7	6,678	61,274	107,899	111,043	194,529
AP Forest Passive Mgmt.	23.20	3,836	183,335	1,677	388,331	39	6,717	65,110	111,735	112,721	196,207
AP Cropland Dry	23.26	9,904	193,239	28,669	417,000	667	7,384	65,110	111,735	112,721	196,207
LS Cropland Wet	23.58	16,680	209,919	53,720	470,720	1,267	8,651	65,110	111,735	112,721	196,207
NE Pastureland Dry	23.63	847	210,765	1,958	472,678	46	8,697	65,110	112,582	112,721	198,165
NP Cropland Dry	23.72	16,896	227,661	44,096	516,774	1,046	9,743	65,110	112,582	112,721	198,165
NE Cropland Wet	24.14	5,130	232,791	18,536	535,310	448	10,191	65,110	112,582	112,721	198,165
MT Forest Passive Mgmt.	27.29	3,204	235,995	887	536,197	24	10,215	68,315	115,786	113,608	199,053
NE Forest Active Mgmt.	28.09	5,804	241,800	3,355	539,552	94	10,309	74,119	121,590	116,963	202,407
NE Cropland Dry	28.76	5,828	247,628	17,723	557,274	510	10,819	74,119	121,590	116,963	202,407
LS Cropland Dry	28.92	8,131	255,759	21,234	578,508	614	11,433	74,119	121,590	116,963	202,407
PC Cropland Dry	30.77	5,281	261,041	13,116	591,624	404	11,837	74,119	121,590	116,963	202,407
PC Cropland Wet	30.81	3,770	264,811	9,348	600,972	288	12,125	74,119	121,590	116,963	202,407
CB Cropland Wet	34.98	38,660	303,471	105,234	706,206	3,681	15,806	74,119	121,590	116,963	202,407
CB Cropland Dry	36.99	39,353	342,823	100,652	806,858	3,723	19,529	74,119	121,590	116,963	202,407
NE Forest Passive Mgmt.	43.33	1,153	343,976	333	807,191	14	19,543	75,271	122,743	117,296	202,740

Cum.=Cumulative. NE=Northeast, LS=Lake States, CB=Corn Belt, NP=Northern Plains, SP=Southern Plains, MT=Mountain, AP=Appalachian, PC=Pacific, DS=Delta States, SE=Southeast.

Table 2—*Cropland Potential for Tree Planting Program by Region and State (thousand acres)*

	Cropland E > T[1]	Cropland LCC[2] V	VI	VII	V+VI+VII (adjusted)	Cropland = W[3]	Total cropland
Northeast	5,300.2	126.2	543.4	182.3	528.178	5,130.0	10,958.4
Connecticut	55.2	0.0	20.2	8.1	17.5		
Delaware	53.0	1.1	0.7	0.0	1.1		
Maine	268.2	0.0	20.8	1.6	13.9		
Maryland	589.4	13.0	66.4	24.2	64.2		
Massachusetts	36.0	12.1	31.4	0.5	27.3		
New Hampshire	9.3	0.8	9.4	9.9	12.5		
New Jersey	384.3	22.4	20.0	17.8	37.3		
New York	1,616.6	56.5	91.3	10.9	98.4		
Pennsylvania	2,214.1	15.4	251.1	106.4	231.2		
Rhode Island	8.4	0.5	1.0	0.0	0.9		
Vermont	65.7	4.4	31.1	2.9	23.8		
Appalachian	9,010.9	73.5	1,022.2	344.1	892.7	6,020.0	15,923.6
Kentucky	2,412.7	0.7	301.3	85.8	240.4		
North Carolina	2,476.4	2.3	178.5	62.1	150.6		
Tennessee	2,806.9	47.3	305.8	76.9	266.6		
Virginia	1,191.5	12.5	137.0	50.8	124.2		
West Virginia	123.4	10.7	99.6	68.5	110.9		
Southeast	6,706.5	153.5	351.3	268.1	479.2	4,690.0	11,875.7
Alabama	2,558.8	45.0	121.6	49.4	133.9		
Florida	375.9	9.5	115.2	178.9	188.2		
Georgia	3,072.7	96.3	69.3	28.0	120.0		
South Carolina	699.1	2.7	45.2	11.8	37.0		
Lake States	7,347.7	108.8	963.6	191.6	783.7	16,680.0	24,811.4
Michigan	1,204.4	38.3	169.5	43.0	155.5		
Minnesota	3,023.2	34.1	200.3	58.3	181.5		
Wisconsin	3,120.1	36.4	593.8	90.3	446.7		
Corn Belt	38,103.8	196.2	1,507.8	310.3	1,248.9	38,660.0	78,012.7
Illinois	10,227.3	64.3	423.3	54.5	336.1		
Indiana	4,687.4	13.5	179.8	9.5	125.7		
Iowa	12,261.0	71.4	456.2	158.8	425.6		
Missouri	7,223.7	38.5	299.3	69.8	252.7		
Ohio	3,704.4	8.5	149.2	17.7	108.7		

		Cropland LCC[2]					
	Cropland E > T[1]	V	VI	VII	V+VI+VII (adjusted)	Cropland = W[3]	Total cropland
Delta States	8,457.0	336.0	237.9	103.1	419.7	16,350.0	25,226.7
Arkansas	3,276.1	28.4	23.4	10.5	38.6		
Louisiana	2,171.0	114.7	6.3	1.0	75.6		
Mississippi	3,009.9	192.9	208.2	91.6	305.5		
Northern Plains	14,067.0	465.3	3,932.1	165.3	2,828.9	7,160.0	24,055.9
Kansas	4,475.6	78.7	731.3	31.7	521.9		
Nebraska	4,620.7	41.5	1,214.3	23.1	792.9		
North Dakota	2,579.1	271.1	1,229.3	94.6	988.9		
South Dakota	2,391.6	74.0	757.2	15.9	525.2		
Southern Plains	6,294.0	454.1	1,196.9	126.5	1,102.1	6,050.0	13,446.1
Oklahoma	1,395.5	108.4	398.0	11.2	320.9		
Texas	4,898.5	345.7	798.9	115.3	781.1		
Mountain	5,675.5	358.2	3,518.2	630.9	2,794.5	2,470.0	10,940.0
Arizona	0.0	0.0	6.0	0.3	3.9		
Colorado	1,072.3	80.6	1,219.0	59.0	842.3		
Idaho	2,454.2	54.3	359.1	74.7	302.6		
Montana	1,714.3	83.3	1,188.5	288.6	967.4		
Nevada	0.0	53.4	104.8	75.5	144.9		
New Mexico	118.1	0.4	251.9	36.2	178.9		
Utah	109.2	28.4	134.1	69.3	143.7		
Wyoming	207.4	57.8	254.8	27.3	210.7		
Pacific	4,584.2	84.9	730.0	309.3	697.0	3,770.0	9,051.2
California	503.7	1.8	200.8	170.1	231.1		
Oregon	1,577.4	72.0	147.3	43.9	163.2		
Washington	2,503.1	11.1	381.9	95.3	302.7		
TOTAL	105,546.8	2,356.7	14,003.4	2,631.5	11,774.8	106,980.0	224,301.6

[1] Cropland with erosion rates (E) greater than the tolerance rate (T).

[2] Cropland in land classification categories V or higher (that is, unsuitable for sustained agriculture), adjusted for land already included in cropland E>T.

[3] Cropland with wet soils (subclass "w").

Table 4—*Cropland, Wet Soils: Treatment Type, Yield, and Cost by Region*

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ ac/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/ year)[8]	Weighted Yield[9]
Northeast	149	white/Norway spruce	0.4	105	70	10	7.7	4.04	1.62
		loblolly pine	0.2	150	45	14	3.1	3.26	0.65
		black spruce	0.2	100	70	12	7.7	4.62	0.92
		mixed species	0.2	90	120	12	3.9	2.11	0.42
		Total							3.61
Lake States	107	red pine	0.2	93	120	12	3.7	2.06	0.41
		white/Norway spruce	0.4	120	70	10	8.4	5.04	2.02
		white pine	0.2	98	120	8	3.7	1.45	0.29
		mixed species	0.2	95	100	12	4.4	2.51	0.50
		Total							3.22
Corn Belt	139	mixed hardwoods(oak)	0.8	82	100	16	4.4	2.89	2.31
		mixed softwoods(pine)	0.2	93	120	12	3.7	2.06	0.41
		Total							2.72
Northern Plains	97	black walnut	0.5	60	50	15	4.4	1.98	0.99
		Colorado blue spruce	0.3	95	70	12	8.4	4.79	1.44
		hardwoods (ash)	0.2	55	100	18	4.4	2.18	0.44
		Total							2.86
Appalachian	62	loblolly pine	0.9	162	45	14	3.1	3.52	3.16
		loblolly/shortleaf	0.1	143	50	14	3.1	3.10	0.31
		Total							3.47
Southeast	61	loblolly pine	0.5	157	45	14	3.1	3.41	1.70
		slash pine	0.3	140	30	17	3.1	3.69	1.11
		longleaf pine	0.1	95	55	17	3.1	2.50	0.25
		hardwoods	0.1	130	70	16	3.1	3.22	0.32
		Total							3.38

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ac/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/year)[8]	Weighted Yield[9]
Delta States	70	loblolly pine	0.7	170	45	14	2.7	3.21	2.25
		hardwoods	0.2	130	70	16	3.9	4.06	0.81
		slash pine	0.1	162	30	17	2.7	3.72	0.37

		Total							2.62
Southern Plains	57	loblolly pine	1.0	150	45	14	2.7	2.84	2.84
Mountain	70	ponderosa pine	1.0	129	100	11	5.3	3.76	3.76
Pacific	180	Douglas-fir	0.3	145	100	14	2	2.03	0.61
		red alder	0.3	170	30	12	4.1	4.18	1.25
		ponderosa pine	0.4	80	100	11	3.5	1.54	0.62

		Total							2.48

1 Cost of all establishment activities, including land preparation, seedlings, planting, and followup where required.

2 Tree species to be planted.

3 The portion of acreage planted in each tree species.

4 Cubic feet of merchantable (salable) wood yielded per acre per year.

5 Typical rotation cycle or maturation period for each species. (This factor is not used in calculations. All capital costs are amortized over 40 years.)

6 Pounds of carbon contained in a cubic foot of merchantable wood.

7 Factor for converting from carbon in merchantable wood to carbon in forest ecosystem.

8 Tons of carbon per acre per year captured by tree planting or other practice.

9 Carbon yield of tree planting weighted to reflect relative area weight of each species. Total of weighted yields reflects average yield of carbon per acre per year for entire region.

Table 5—*Cropland, Dry Soils: Treatment Type, Yield, and Cost by Region*

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ acre/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/ year)[8]	Weighted yield[9]
Northeast	151	white/Norway spruce	0.3	95	70	10	7.7	3.66	1.10
		loblolly pine	0.2	125	45	14	3.1	2.71	0.54
		black spruce	0.2	95	70	12	7.7	4.39	0.88
		red pine	0.1	80	120	12	3.1	1.49	0.15
		mixed species	0.2	80	120	12	3.9	1.87	0.37

		Total							3.04
Lake States	103	red pine	0.5	93	120	12	3.7	2.06	1.03
		white/Norway spruce	0.2	111	70	10	8.4	4.66	0.93
		white pine	0.1	98	120	8	3.7	1.45	0.15
		mixed species	0.2	95	100	12	4.4	2.51	0.50

		Total							2.61
Corn Belt	133	mixed hardwoods(oak)	0.6	82	100	16	4.4	2.89	1.73
		mixed softwoods(pine)	0.4	93	120	12	3.7	2.06	0.83

		Total							2.56
Northern Plains	97	black walnut	0.5	50	50	15	4.4	1.65	0.83
		Colorado blue spruce	0.3	95	70	12	8.4	4.79	1.44
		hardwoods (ash)	0.2	44	100	18	4.4	1.74	0.35

		Total							2.61
Appalachian	62	loblolly pine	0.9	135	45	14	3.1	2.93	2.64
		loblolly shortleaf	0.1	119	50	14	3.1	2.58	0.26

		Total							2.89
Southeast	58	loblolly pine	0.6	131	45	14	3.1	2.84	1.71
		slash pine	0.3	117	30	17	3.1	3.08	0.92
		longleaf pine	0.1	83	55	17	3.1	2.19	0.22

		Total							2.85

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/acre/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/year)[8]	Weighted yield[9]
Delta States	69	loblolly pine	0.9	142	45	14	2.7	2.68	2.42
		slash pine	0.1	135	30	17	2.7	3.10	0.31
		Total							2.73
Southern Plains	57	loblolly pine	1.0	125	45	14	2.7	2.36	2.36
Mountain	70	ponderosa pine	1.0	129	100	11	5.3	3.76	3.76
Pacific	180	Douglas fir	0.6	145	100	14	3.5	3.55	2.13
		pine(ponderosa/knobcone)	0.4	80	100	11	2.0	0.88	0.35
		Total							2.48

1 Cost of all establishment activities, including land preparation, seedlings, planting, and followup where required.

2 Tree species to be planted.

3 The portion of acreage planted in each tree species.

4 Cubic feet of merchantable (salable) wood yielded per acre per year.

5 Typical rotation cycle or maturation period for each species. (This factor is not used in calculations. All capital costs are amortized over 40 years.)

6 Pounds of carbon contained in a cubic foot of merchantable wood.

7 Factor for converting from carbon in merchantable wood to carbon in forest ecosystem.

8 Tons of carbon per acre per year captured by tree planting or other practice.

9 Carbon yield of tree planting weighted to reflect relative area weight of each species. Total of weighted yields reflects average yield of carbon per acre per year for entire region.

Table 6—*Pastureland, Wet Soils: Treatment Type, Yield, and Cost by Region*

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/acre/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/year)[8]	Weighted yield[9]
Northeast	196	white/Norway spruce	0.4	89	70	10	7.0	3.12	1.25
		loblolly pine	0.2	128	45	14	2.6	2.32	0.46
		black spruce	0.2	85	70	12	7.0	3.57	0.71
		mixed species	0.2	77	120	12	3.6	1.65	0.33
		Total							2.76
Lake States	105	red pine	0.2	79	120	12	3.5	1.66	0.33
		white/Norway spruce	0.4	102	70	10	7.6	3.88	1.55
		white pine	0.2	83	120	8	3.5	1.17	0.23
		mixed species	0.2	81	100	12	4.1	1.99	0.40
		Total							2.51
Corn Belt	186	mixed hardwoods(oak)	0.8	70	100	16	4.0	2.23	1.78
		mixed softwoods(pine)	0.2	79	120	12	3.5	1.66	0.33
		Total							2.12
Northern Plains	102	black walnut	0.5	51	50	15	4.1	1.57	0.78
		Colorado blue spruce	0.3	81	70	12	7.6	3.68	1.10
		hardwoods (ash)	0.2	47	100	18	4.1	1.73	0.35
		Total							2.23
Appalachian	89	loblolly pine	0.9	138	45	14	2.6	2.51	2.26
		loblolly/shortleaf	0.1	122	50	14	2.6	2.21	0.22
		Total							2.48
Southeast	67	loblolly pine	0.5	133	45	14	2.6	2.43	1.21
		slash pine	0.3	119	30	17	2.6	2.63	0.79
		longleaf pine	0.1	81	55	17	2.6	1.78	0.18
		hardwoods	0.1	111	70	16	3.2	2.83	0.28
		Total							2.46

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ acre/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/ year)[8]	Weighted yield[9]
Delta States	77	loblolly pine	0.7	145	45	14	2.8	2.83	1.98
		hardwoods	0.2	111	70	16	4.0	3.54	0.71
		slash pine	0.1	138	30	17	2.8	3.28	0.33

		Total							2.31
Southern Plains	63	loblolly pine	1.0	128	45	14	2.8	2.50	2.50
Mountain	69	ponderosa pine	1.0	110	100	11	5.1	3.08	3.08
Pacific	215	Douglas-fir	0.3	123	100	14	2.0	1.73	0.52
		red alder	0.3	145	30	12	3.8	3.29	0.99
		ponderosa pine	0.4	68	100	11	2.0	0.75	0.30

		Total							1.81

1 Cost of all establishment activities, including land preparation, seedlings, planting, and followup where required.

2 Tree species to be planted.

3 The portion of acreage planted in each tree species.

4 Cubic feet of merchantable (salable) wood yielded per acre per year.

5 Typical rotation cycle or maturation period for each species. (This factor is not used in calculations. All capital costs are amortized over 40 years.)

6 Pounds of carbon contained in a cubic foot of merchantable wood.

7 Factor for converting from carbon in merchantable wood to carbon in forest ecosystem.

8 Tons of carbon per acre per year captured by tree planting or other practice.

9 Carbon yield of tree planting weighted to reflect relative area weight of each species. Total of weighted yields reflects average yield of carbon per acre per year for entire region.

Table 7—*Pastureland, Dry Soils: Treatment Type, Yield, and Cost by Region*

	Treatment cost \$/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ ac/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/ year)[8]	Weighted yield[9]
Northeast	196	white/Norway spruce	0.3	81	70	10	7.0	2.83	0.85
		loblolly pine	0.2	106	45	14	2.6	1.93	0.39
		black spruce	0.2	81	70	12	7.0	3.39	0.68
		red pine	0.1	68	120	12	2.6	1.06	0.11
		mixed species	0.2	68	120	12	3.6	1.47	0.29
		Total							2.31
Lake States	105	red pine	0.5	79	120	12	3.5	1.66	0.83
		white/Norway spruce	0.2	94	70	10	7.6	3.59	0.72
		white pine	0.1	83	120	8	3.5	1.17	0.12
		mixed species	0.2	81	100	12	4.1	1.99	0.40
		Total							2.06
Corn Belt	186	mixed hardwoods(oak)	0.6	70	100	16	4.0	2.23	1.34
		mixed softwoods(pine)	0.4	79	120	12	3.5	1.66	0.66
		Total							2.00
Northern Plains	102	black walnut	0.5	43	50	15	4.1	1.31	0.65
		Colorado blue spruce	0.3	81	70	12	7.6	3.68	1.10
		hardwoods (ash)	0.2	37	100	18	4.1	1.38	0.28
		Total							2.03
Appalachian	89	loblolly pine	0.9	115	45	14	2.6	2.09	1.88
		loblolly shortleaf	0.1	101	50	14	2.6	1.84	0.18
		Total							2.06
Southeast	67	loblolly pine	0.6	111	45	14	2.6	2.03	1.22
		slash pine	0.3	99	30	17	2.6	2.20	0.66
		longleaf pine	0.1	71	55	17	2.6	1.56	0.16
		Total							2.03

	Treatment cost $/acre[1]	Species[2]	Area wt.[3]	Merch. wood (cu ft/ ac/yr)[4]	Rotation years[5]	Carbon (lbs/cu ft of wood)[6]	Total carbon conversion ratio[7]	Yield of carbon (tons/acre/ year)[8]	Weighted yield[9]
Delta States	77	loblolly pine	0.9	121	45	14	2.8	2.37	2.13
		slash pine	0.1	115	30	17	2.8	2.73	0.27

		Total							2.40
Southern Plains	63	loblolly pine	1.0	106	45	14	2.8	2.08	2.08
Mountain	69	ponderosa pine	1.0	110	100	11	5.1	3.08	3.08
Pacific	215	Douglas fir	0.6	123	100	14	2.0	1.73	1.04
		pine(ponderosa/ knobcone)	0.4	68	100	11	3.1	1.16	0.46

		Total							1.50

[1] Cost of all establishment activities, including land preparation, seedlings, planting, and followup where required.

[2] Tree species to be planted.

[3] The portion of acreage planted in each tree species.

[4] Cubic feet of merchantable (salable) wood yielded per acre per year.

[5] Typical rotation cycle or maturation period for each species. (This factor is not used in calculations. All capital costs are amortized over 40 years.)

[6] Pounds of carbon contained in a cubic foot of merchantable wood.

[7] Factor for converting from carbon in merchantable wood to carbon in forest ecosystem.

[8] Tons of carbon per acre per year captured by tree planting or other practice.

[9] Carbon yield of tree planting weighted to reflect relative area weight of each species. Total of weighted yields reflects average yield of carbon per acre per year for entire region.

Table 8—*Forestland, All Soils: Treatment Type, Cost, and Incremental Yield*

	Planting trees[1]					Passive management[2]					Active management[3]				
	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)
	- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)	
Northeast	159	2,263	2,422	140.0	70.0	254	898	1,153	4.0	16.85	29	5,775	5,804	40.3	33.7
Connecticut	0	21	21	140.0	70.0	5	10	15	4.0		2	236	237	40.3	33.7
Delaware	138	90	228	140.0	70.0	0	3	3	4.0		0	23	23	40.3	33.7
Maine	4	397	402	140.0	70.0	8	34	42	4.0		1	1,384	1,384	40.3	33.7
Maryland	3	299	302	140.0	70.0	18	98	116	4.0		1	245	246	40.3	33.7
Massachusetts	0	46	46	140.0	70.0	1	20	21	4.0		1	359	361	40.3	33.7
New Hampshire	3	78	81	140.0	70.0	7	23	30	4.0		3	352	355	40.3	33.7
New Jersey	0	26	26	140.0	70.0	1	102	103	4.0		0	88	89	40.3	33.7
New York	1	386	387	140.0	70.0	116	166	282	4.0		6	1,352	1,358	40.3	33.7
Pennsylvania	10	829	840	140.0	70.0	75	401	477	4.0		9	1,274	1,284	40.3	33.7
Rhode Island	0	19	19	140.0	70.0	1	8	8	4.0		0	48	48	40.3	33.7
Vermont	0	71	71	140.0	70.0	23	35	58	4.0		6	413	419	40.3	33.7
Appalachian	270	6,394	6,664	115.9	48.4	1,890	1,946	3,836	4.0	20.15	191	3,573	3,764	46.9	40.3
Kentucky	47	763	810	140.7	53.4	500	186	686	4.0		36	738	774	47.8	42.2
North Carolina	49	4,252	4,302	109.0	46.5	66	218	284	4.0		21	774	795	47.1	39.4
Tennessee	79	419	498	140.7	53.4	482	222	703	4.0		72	963	1,035	47.8	42.2
Virginia	83	826	909	109.0	46.5	227	414	641	4.0		57	809	866	47.1	39.4
West Virginia	12	134	146	140.0	70.0	615	907	1,522	4.0		5	288	293	40.3	33.7
Southeast	569	9,316	9,885	120.5	49.0	246	1,068	1,314	4.0	20.22	208	3,761	3,969	47.4	40.4
Alabama	288	3,314	3,602	140.7	53.4	82	199	281	4.0		86	1,382	1,468	47.8	42.2
Florida	138	1,456	1,593	109.0	46.5	99	262	361	4.0		74	496	570	47.1	39.4
Georgia	65	2,342	2,407	109.0	46.5	42	591	632	4.0		22	1,067	1,089	47.1	39.4
South Carolina	79	2,205	2,284	109.0	46.5	24	16	39	4.0		26	816	842	47.1	39.4
Lake States	121	3,424	3,545	132.0	77.7	1,188	529	1,717	4.0	21.45	54	1,733	1,788	31.5	42.9
Michigan	11	915	925	132.0	77.7	52	288	341	4.0		5	527	533	31.5	42.9
Minnesota	58	1,857	1,914	132.0	77.7	194	123	316	4.0		19	624	643	31.5	42.9
Wisconsin	52	653	705	132.0	77.7	942	118	1,059	4.0		30	582	612	31.5	42.9

	Planting trees[1]					Passive management[2]					Active management[3]				
	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)
	- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)	
Corn Belt	333	1,502	1,835	132.0	77.7	2,786	883	3,669	4.0	21.45	229	1,894	2,124	31.5	42.9
Illinois	13	254	267	132.0	77.7	544	163	707	4.0		5	198	203	31.5	42.9
Indiana	43	295	337	132.0	77.7	161	138	299	4.0		15	289	303	31.5	42.9
Iowa	63	81	143	132.0	77.7	438	40	477	4.0		24	88	112	31.5	42.9
Missouri	207	334	540	132.0	77.7	1,199	267	1,466	4.0		176	805	982	31.5	42.9
Ohio	8	539	547	132.0	77.7	445	276	720	4.0		10	514	524	31.5	42.9
Delta States	512	2,668	3,180	140.7	53.4	470	1,136	1,606	4.0	21.10	335	2,118	2,454	47.8	42.2
Arkansas	126	830	956	140.7	53.4	157	397	555	4.0		146	858	1,004	47.8	42.2
Louisiana	163	467	629	140.7	53.4	139	371	510	4.0		86	376	461	47.8	42.2
Mississippi	223	1,372	1,595	140.7	53.4	174	367	541	4.0		104	885	989	47.8	42.2
Northern Plains	4	23	28	132.0	77.7	160	54	214	4.0	17.84	40	56	96	27.7	35.7
Kansas	4	12	17	132.0	77.7	35	13	49	4.0		11	32	43	31.5	42.9
Nebraska	0	11	11	132.0	77.7	104	28	132	4.0		6	13	19	31.5	42.9
North Dakota	0	0	0	132.0	77.7	16	5	21	4.0		2	3	5	31.5	42.9
South Dakota	0	0	0	153.0	36.0	4	8	12	4.0		21	8	29	19.0	19.0
Southern Plains	740	1,276	2,016	140.7	53.4	480	447	927	4.0	21.10	318	579	897	47.8	42.2
Oklahoma	159	101	260	140.7	53.4	334	278	612	4.0		108	93	201	47.8	42.2
Texas	581	1,175	1,756	140.7	53.4	147	169	315	4.0		210	486	696	47.8	42.2
Mountain	303	535	838	153.0	36.0	2,755	449	3,204	4.0	9.50	471	555	1,026	19.0	19.0
Arizona	0	0	0	153.0	36.0	35	0	35	4.0		12	36	49	19.0	19.0
Colorado	60	28	88	153.0	36.0	392	180	571	4.0		68	93	161	19.0	19.0
Idaho	113	323	436	153.0	36.0	45	52	97	4.0		72	221	293	19.0	19.0
Montana	96	161	257	153.0	36.0	142	53	196	4.0		53	126	179	19.0	19.0
Nevada	0	14	14	153.0	36.0	58	7	65	4.0		2	5	7	19.0	19.0
New Mexico	35	1	36	153.0	36.0	950	83	1,033	4.0		209	58	267	19.0	19.0
Utah	0	0	0	153.0	36.0	1,005	62	1,067	4.0		15	7	22	19.0	19.0
Wyoming	0	7	7	153.0	36.0	128	13	141	4.0		39	9	48	19.0	19.0

	Planting trees[1]					Passive management[2]					Active management[3]				
	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)	Grazed	Ungrazed	Total	Treatment cost	Yield of Merch. wood (cu ft/ acre/yr)
	- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)		- -(thousand acres)- -			($/acre)	
Pacific	764	2,814	3,578	247.4	184.3	1,180	1,861	3,041	4.0	19.10	409	1,961	2,370	35.9	38.2
California	371	922	1,294	159.7	148.5	618	1,007	1,625	4.0		120	474	594	13.0	36.7
Oregon	246	1,017	1,263	297.1	204.6	414	553	967	4.0		111	660	771	43.6	38.7
Washington	147	874	1,022	297.1	204.6	148	300	448	4.0		178	827	1,006	43.6	38.7

[1] Forestland requiring substantial planting of new trees.

[2] Forestland requiring minimal protection, such as restricting grazing, allowing natural regeneration, and so forth.

[3] Forestland requiring timber stand improvement and other silvicultural practices.

Table 9—*Forestland Carbon Yields by Treatment Type and Region*

						Planting trees		Active management		Passive management	
	Species[1]	Area wt[2]	Rotation years[3]	Carbon (lbs/cu ft of wood)[4]	Total carbon conversion ratio[5]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]
Northeast	white/Norway spruce	0.3	70	10	3.7	21.0	0.4	10.1	0.2	5.1	0.1
	loblolly pine	0.2	45	14	1.9	14.0	0.2	6.7	0.1	3.4	0.0
	black spruce	0.2	70	12	3.7	14.0	0.3	6.7	0.1	3.4	0.1
	red pine	0.1	120	12	1.9	7.0	0.1	3.4	0.0	1.7	0.0
	mixed species	0.2	120	12	2.8	14.0	0.2	6.7	0.1	3.4	0.1
	Total					70.0	1.2	33.7	0.6	16.9	0.3
Lake States	red pine	0.5	120	12	3.7	38.9	0.9	21.5	0.5	10.7	0.2
	white/Norway spruce	0.2	70	10	8.4	15.5	0.7	8.6	0.4	4.3	0.2
	white pine	0.1	120	8	3.7	7.8	0.1	4.3	0.1	2.1	0.0
	mixed species	0.2	100	12	4.4	15.5	0.4	8.6	0.2	4.3	0.1
	Total					77.7	2.0	42.9	1.1	21.5	0.6
Corn Belt	mixed hardwoods (oak)	0.6	100	16	4.4	46.6	1.6	25.7	0.9	12.9	0.5
	mixed softwoods (pine)	0.4	120	12	3.7	31.1	0.7	17.2	0.4	8.6	0.2
	Total					77.7	2.3	42.9	1.3	21.5	0.6
Northern Plains	black walnut	0.5	50	15	4.4	38.9	1.3	17.8	0.6	8.9	0.3
	Colorado blue spruce	0.3	70	12	8.4	23.3	1.2	10.7	0.5	5.4	0.3
	hardwoods (ash)	0.2	100	18	4.4	15.5	0.6	7.1	0.3	3.6	0.1
	Total					77.7	3.1	35.7	1.4	17.8	0.7
Appalachian	loblolly pine	0.9	45	14	3.1	43.5	0.9	36.3	0.8	18.1	0.4
	loblolly/shortleaf	0.1	50	14	3.1	4.8	0.1	4.0	0.1	2.0	0.0
	Total					48.4	1.0	40.3	0.9	20.2	0.4

						Planting trees		Active management		Passive management	
	Species[1]	Area wt[2]	Rotation years[3]	Carbon (lbs/cu ft of wood)[4]	Total carbon conversion ratio[5]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]	Merch. wood (cu ft/ acre/yr)[6]	Yield of carbon (tons/acre/ year)[7]
Southeast	loblolly pine	0.6	45	14	3.1	29.4	0.6	24.3	0.5	12.1	0.3
	slash pine	0.3	30	17	3.1	14.7	0.4	12.1	0.3	6.1	0.2
	longleaf pine	0.1	55	17	3.1	4.9	0.1	4.0	0.1	2.0	0.1
	Total					49.0	1.2	40.4	1.0	20.2	0.5
Delta States	loblolly pine	0.9	45	14	2.7	48.1	0.9	38.0	0.7	19.0	0.4
	slash pine	0.1	30	17	2.7	5.3	0.1	4.2	0.1	2.1	0.0
	Total					53.4	1.0	42.2	0.8	21.1	0.4
Southern Plains	loblolly pine	1.0	45	14	2.7	53.4	1.0	42.2	0.8	21.1	0.4
Mountain	ponderosa pine	1.0	100	11	5.3	36.0	1.0	19.0	0.6	9.5	0.3
Pacific	Douglas fir	0.6	100	14	3.5	110.6	2.7	22.9	0.6	11.5	0.3
	pine (ponderosa/ knobcone)	0.4	100	11	2.0	73.7	0.8	15.3	0.2	7.6	0.1
	Total					184.3	3.5	38.2	0.7	19.1	0.4

1 Tree species to be planted.

2 The portion of acreage planted in each tree species.

3 Typical rotation cycle or maturation period for each species.

4 Pounds of carbon contained in a cubic foot of merchantable wood.

5 Factor for converting from carbon in merchantable wood to carbon in forest ecosystem.

6 Cubic feet of merchantable (salable) wood yielded per acre per year.

7 Total yield of carbon per acre per year.

Table 10—*Derivation of Land Rent Figures*

	CRP 1-7 rental rate ($/acre)	Model cropland rental rate ($/acre)	Dry cropland private rental ($/acre)			Rental ratio model to private	Dry cropland land value ($/acre)			Ratio of priv. rent to purch. price	Grazing land private rental ($/acre)			Model grazing rent ($/acre)	Model forest rent ($/acre)
			1987	1988	Average		1987	1988	Average		1987	1988	Average		
Northeast	57.84	72.00	41.7	38.8	40.2	1.79	2,967	4,024	3,495.5	0.012	19	19	19.3	35	12
Conneticut	50.00		58.0	46.0	52.0		5,610	7,585	6,597.5	0.008	26	21	23.5		
Delaware	62.63		55.0	44.0	49.5		979	1,152	1,065.5	0.046	35	45	40.0		
Maine	49.31		33.0	32.0	32.5		560	794	677.0	0.048	14	14	14.0		
Maryland	65.27		49.0	41.0	45.0		1,699	2,023	1,861.0	0.024	21	16	18.5		
Massachusetts	47.00		49.0	56.0	52.5		8,403	14,488	11,445.5	0.005	15	18	16.5		
New Hampshire	N/A		N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A		
New Jersey	52.91		38.0	35.0	36.5		6,413	6,855	6,634.0	0.006	23	23	23.0		
New York	56.56		29.0	32.0	30.5		743	840	791.5	0.039	11	12	11.5		
Pennsylvania	61.55		38.0	36.0	37.0		1,356	1,507	1,431.5	0.026	15	13	14.0		
Rhode Island	N/A		N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Vermont	50.00		26.0	27.0	26.5		937	975	956.0	0.028	13	13	13.0		
Appalachian	53.03	61.00	36.6	40.6	38.6	1.58	1,006	1,054	1,029.8	0.037	17	18	17.6	28	10
Kentucky	58.79		47.0	49.0	48.0		817	841	829.0	0.058	21	21	21.0		
North Carolina	45.60		31.0	45.0	38.0		1,049	1,148	1,098.5	0.035	18	25	21.5		
Tennessee	51.46		43.0	41.0	42.0		894	857	875.5	0.048	20	20	20.0		
Virginia	50.25		31.0	36.0	33.5		1,158	1,385	1,271.5	0.026	14	15	14.5		
West Virginia	48.28		31.0	32.0	31.5		1,112	1,037	1,074.5	0.029	11	11	11.0		
Southeast	42.30	51.00	27.5	33.5	30.5	1.67	979	1,079	1,029.0	0.030	16	16	16.0	27	9
Alabama	41.98		29.0	36.0	32.5		592	684	638.0	0.051	12	16	14.0		
Florida	41.56		38.0	45.0	41.5		2,121	2,299	2,210.0	0.019	20	15	17.5		
Georgia	42.74		23.0	31.0	27.0		632	693	662.5	0.041	17	21	19.0		
South Carolina	42.19		20.0	22.0	21.0		571	640	605.5	0.035	14	13	13.5		
Lake States	58.09	65.00	48.0	43.7	45.8	1.42	610	646	628.2	0.073	16	14	14.7	21	7
Michigan	57.81		44.0	39.0	41.5		625	685	655.0	0.063	15	11	13.0		
Minnesota	55.55		49.0	45.0	47.0		546	594	570.0	0.082	13	13	13.0		
Wisconsin	67.17		51.0	47.0	49.0		659	660	659.5	0.074	19	17	18.0		

	CRP 1-7 rental rate ($/acre)	Model cropland rental rate ($/acre)	Dry cropland private rental ($/acre)			Rental ratio model to private	Dry cropland land value ($/acre)			Ratio of priv. rent to purch. price	Grazing land private rental ($/acre)			Model grazing rent ($/acre)	Model forest rent ($/acre)
			1987	1988	Average		1987	1988	Average		1987	1988	Average		
Corn Belt	70.58	81.00	70.6	69.0	69.8	1.16	867	935	901.4	0.077	21	22	21.3	25	9
Illinois	71.80		87.0	83.0	85.0		1,122	1,183	1,152.5	0.074	20	21	20.5		
Indiana	68.38		75.0	71.0	73.0		918	977	947.5	0.077	24	26	25.0		
Iowa	78.14		80.0	85.0	82.5		811	947	879.0	0.094	24	26	25.0		
Missouri	62.63		46.0	50.0	48.0		529	589	559.0	0.086	18	19	18.5		
Ohio	62.96		65.0	56.0	60.5		957	981	969.0	0.062	18	17	17.5		
Delta States	43.46	50.00	36.0	37.0	36.5	1.37	687	692	689.5	0.053	11	13	11.8	16	6
Arkansas	48.81		37.0	36.0	36.5		580	599	589.5	0.062	12	15	13.5		
Louisiana	43.45		38.0	43.0	40.5		926	886	906.0	0.045	10	11	10.5		
Mississippi	41.86		33.0	32.0	32.5		555	591	573.0	0.057	10	13	11.5		
Northern Plains	46.28	52.00	30.8	26.8	28.8	1.81	329	355	342.0	0.084	8	7	7.3	13	5
Kansas	52.57		26.0	29.0	27.5		349	370	359.5	0.076	9	10	9.5		
Nebraska	55.13		43.0	35.0	39.0		400	454	427.0	0.091	8	6	7.0		
North Dakota	38.22		28.0	23.0	25.5		320	324	322.0	0.079	7	7	7.0		
South Dakota	39.96		26.0	20.0	23.0		246	273	259.5	0.089	6	5	5.5		
Southern Plains	40.12	47.00	23.0	25.0	24.0	1.96	623	601	612.0	0.039	6	7	6.5	13	4
Oklahoma	42.39		25.0	27.0	26.0		461	455	458.0	0.057	7	9	8.0		
Texas	39.45		21.0	23.0	22.0		785	747	766.0	0.029	5	5	5.0		
Mountain	39.66	45.00	14.7	20.9	17.8	2.53	318	329	323.4	0.055	8	9	8.1	20	7
Arizona	N/A		N/A	N/A	N/A		N/A	N/A	N/A	N/A	N/A	N/A	N/A		
Colorado	40.86		12.0	15.0	13.5		281	298	289.5	0.047	5	5	5.0		
Idaho	45.20		32.0	39.0	35.5		444	464	454.0	0.078	13	13	13.0		
Montana	37.45		18.0	20.0	19.0		246	255	250.5	0.076	2	3	2.5		
Nevada	40.00		2.0	7.0	4.5		382	382	382.0	0.012	16	22	19.0		
New Mexico	37.81		13.0	23.0	18.0		396	391	393.5	0.046	4	2	3.0		
Utah	40.05		13.0	17.0	15.0		314	340	327.0	0.046	10	12	11.0		
Wyoming	38.52		13.0	25.0	19.0		161	174	167.5	0.113	3	3	3.0		
Pacific	49.19	58.00	45.0	39.0	42.0	1.38	1,026	1,108	1,066.7	0.039	10	8	9.0	12	4
California	48.53		60.0	30.0	45.0		1,813	2,000	1,906.5	0.024	11	12	11.5		
Oregon	49.03		36.0	42.0	39.0		646	684	665.0	0.059	13	8	10.5		
Washington	49.71		39.0	45.0	42.0		618	639	628.5	0.067	7	3	5.0		

Table 11—*Program Statistics by Percentage Reduction From 1.43 Billion Short Tons per Year*

Annual CO_2 offset (percent/millions of short tons)	Land requirement (millions of acres)	Total annual cost (billion $)	Average cost ($/ton carbon)
5 / 72	36.9	0.7	9.72
10 /143	70.9	1.7	12.02
20 /286	138.4	4.5	15.73
30 /429	197.6	7.7	17.91

Table 12—*Regional Land Areas by Percentage Reduction From 1.43 Billion Short Tons per Year*

	Acres included in first:			
	5%	10%	20%	30%
Northeast	0	0	1,707	4,129
Appalachia	0	7,105	24,450	38,190
Southeast	800	7,688	26,073	26,073
Lake States	5,466	7,872	9,660	13,980
Corn Belt	3,959	7,628	12,594	17,826
Delta States	5,417	7,023	17,603	35,830
Northern Plains	2,584	2,584	2,584	9,744
Southern Plains	7,906	7,906	15,975	15,974
Mountain	1,819	13,785	13,785	14,623
Pacific	8,989	8,989	9,909	10,113

Appendix B—Figures

Figure 1

USDA Farm Production Regions

Figure 2

Total Annual Cost of Carbon Sequestering

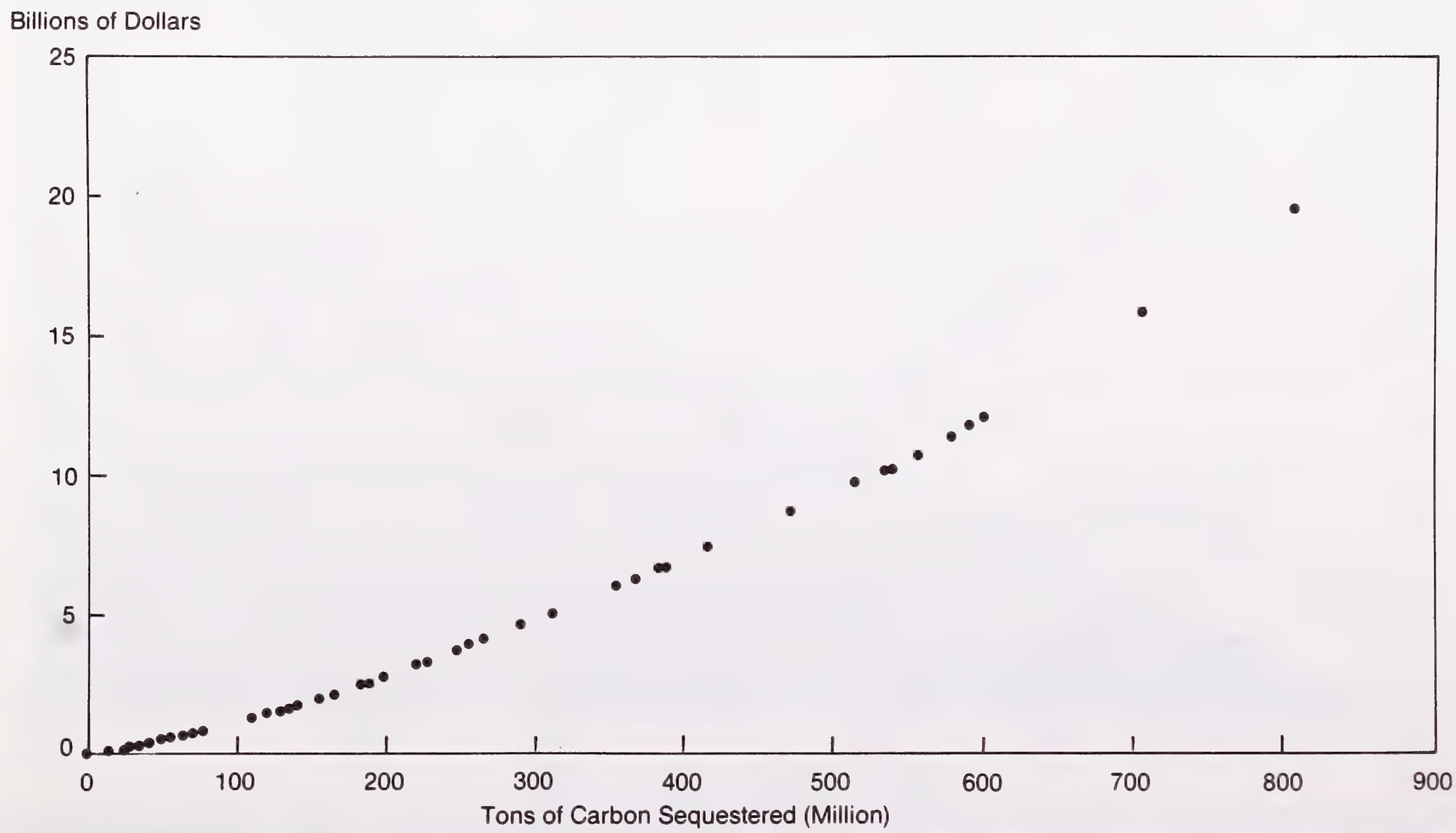


Figure 3

Marginal Cost of Carbon Sequestering (Dollars/Ton of Carbon at Margin)

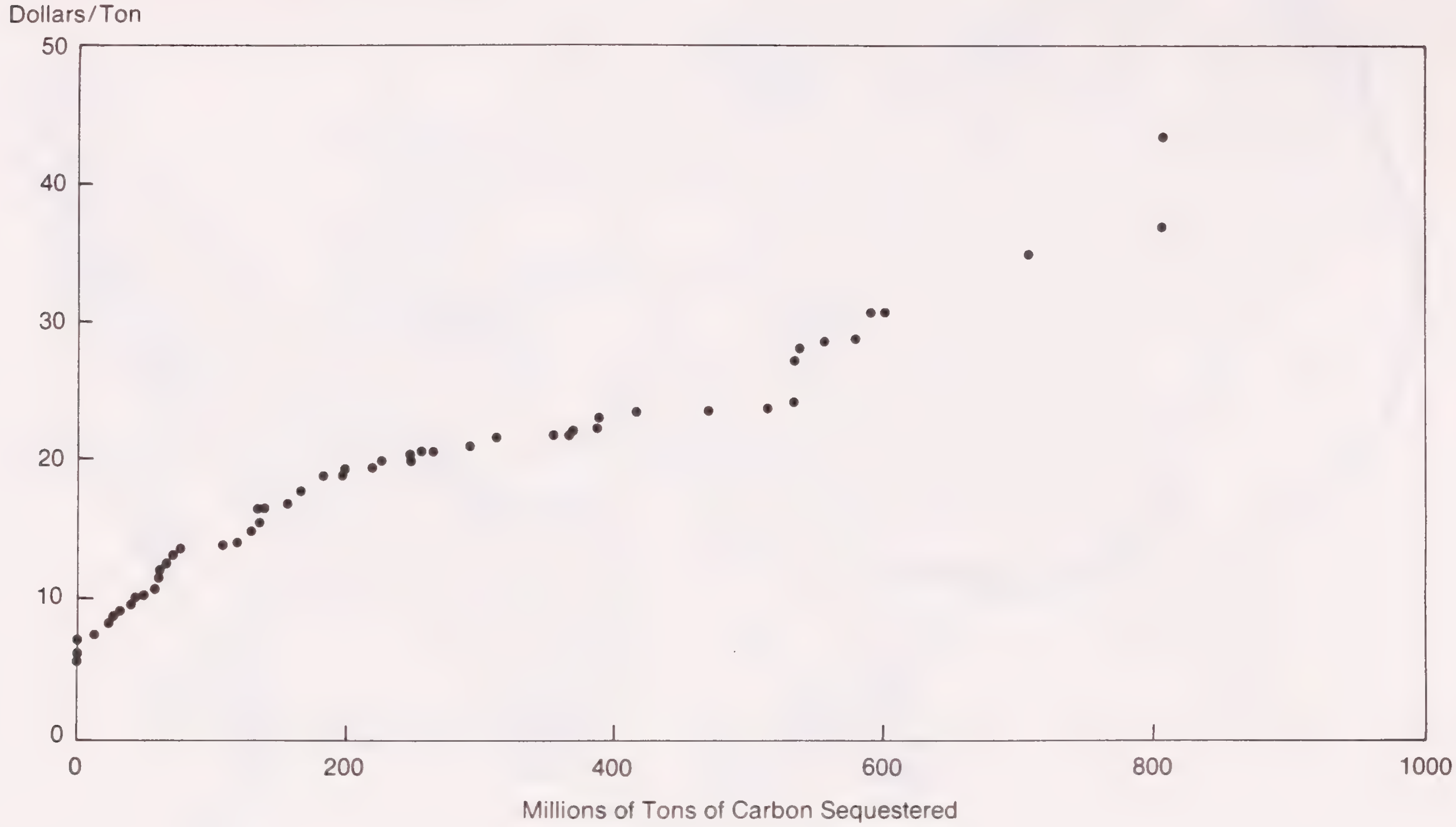


Figure 4

Acreage Requirements by Land Type (Millions of Acres)

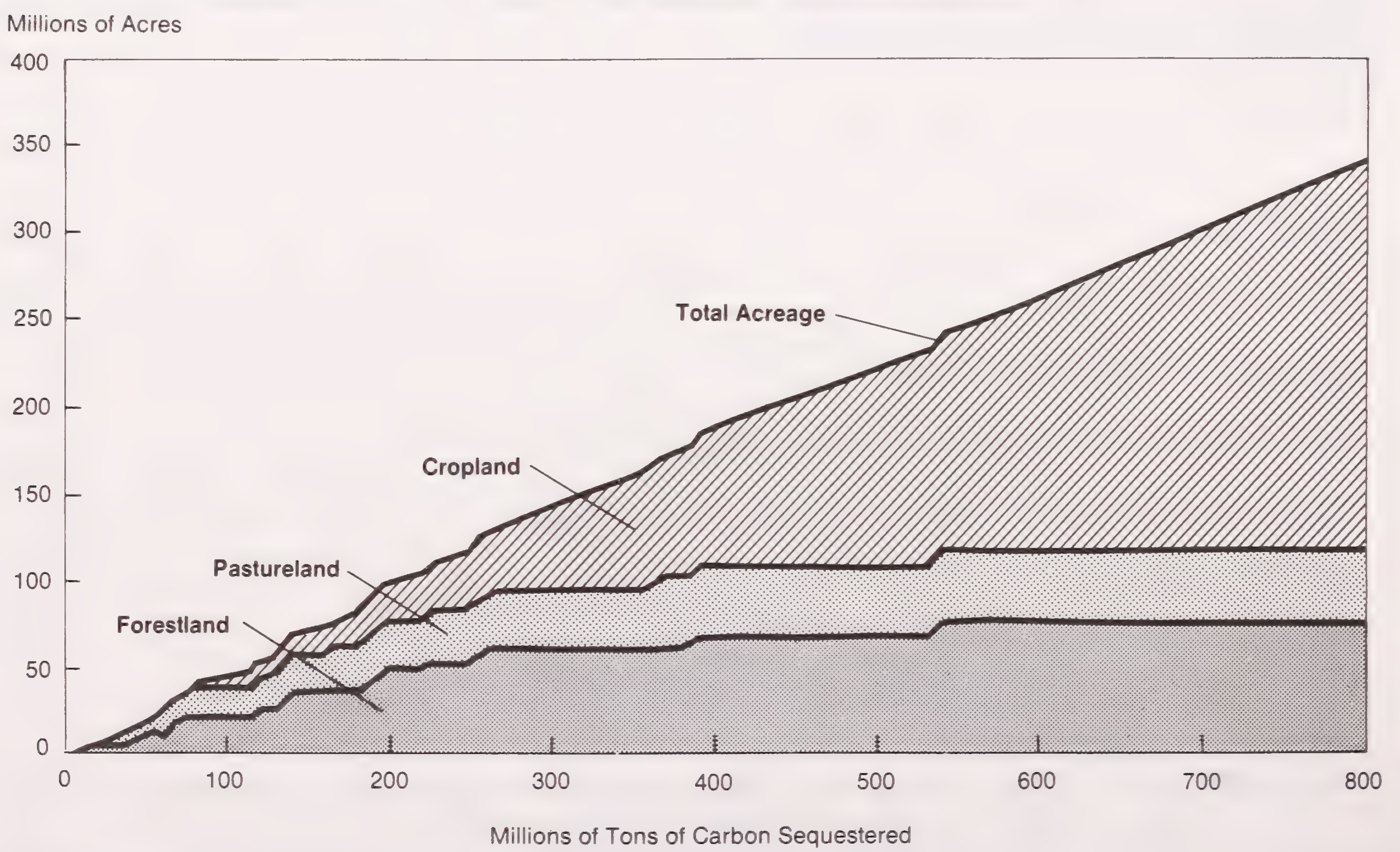


Figure 5

Carbon Sequestration by Land Type (Millions of Tons of Carbon Annually)

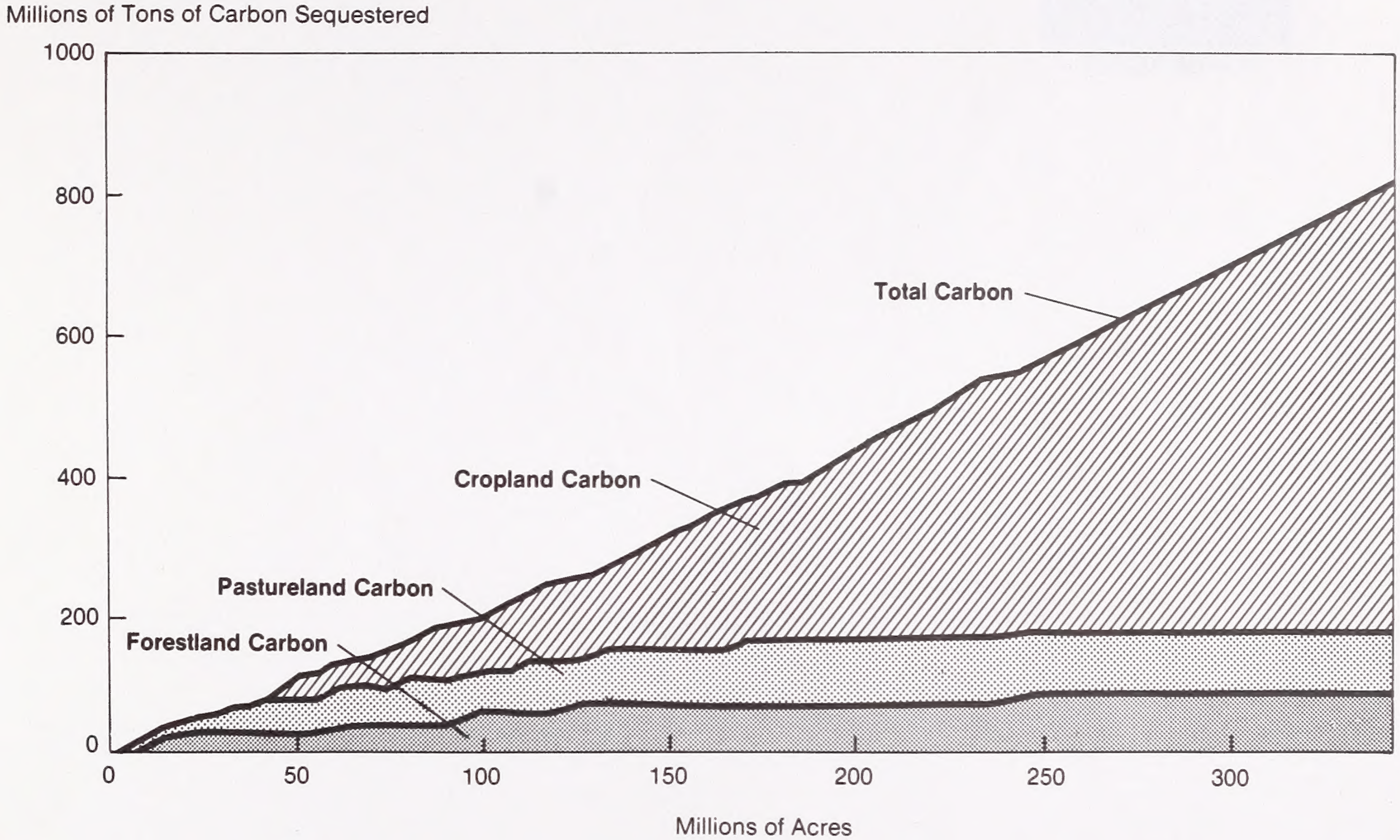
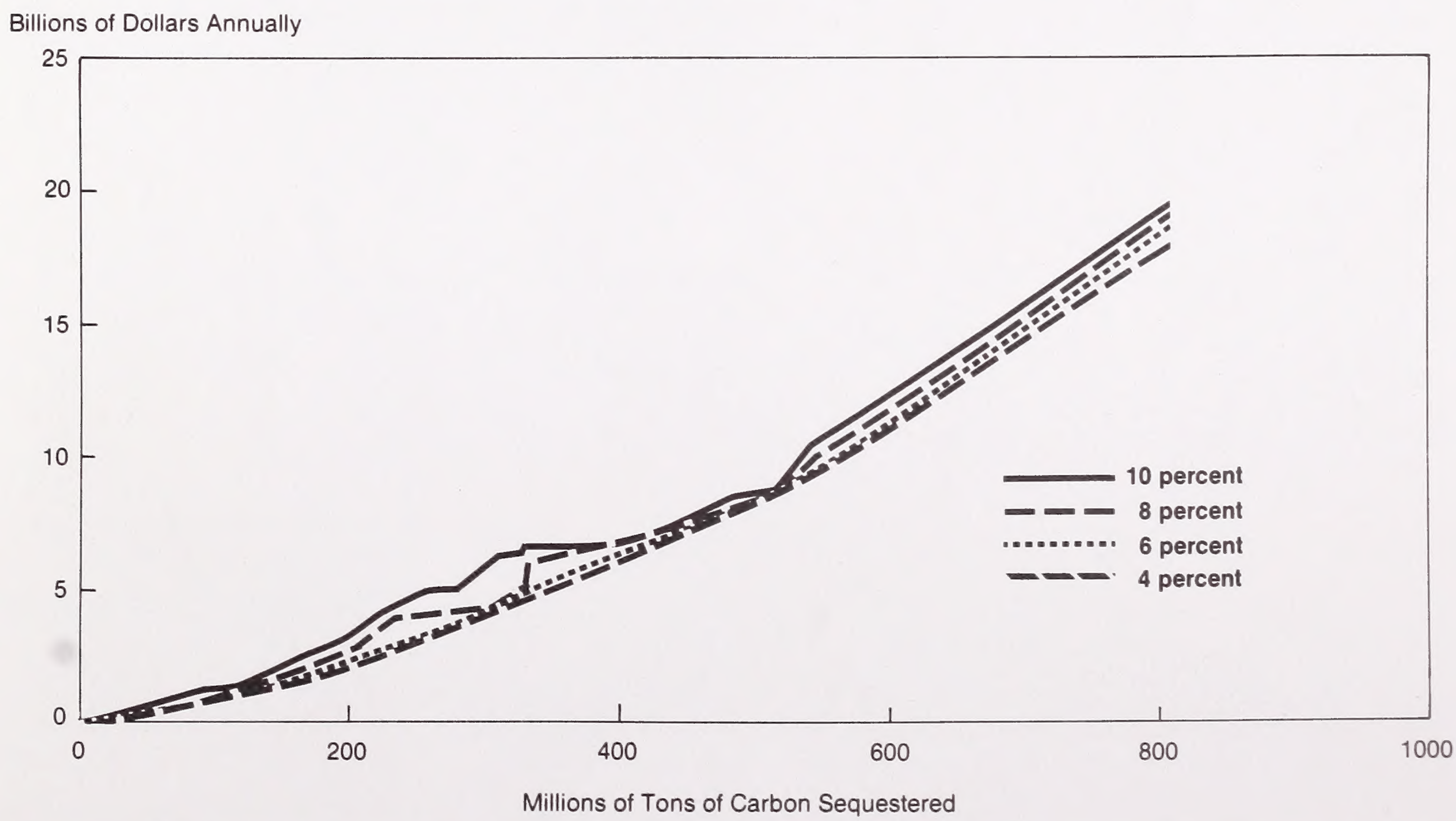


Figure 6

Effect of Discount Rate on Total Costs, Capital Recovery Over 40 Years



U.S. GOVERNMENT PRINTING OFFICE: 1990 0—862-946